

1 Basic concepts and definitions

It called *steel* alloy of iron with carbon, wherein the carbon contains from hundredths to 2%. In addition, the steel also contains manganese, silicon, sulfur, phosphorus and other chemical elements.

Steel metallurgy methods is the science of making steel with desired properties in amounts having industrial value.

Steel is the main structural material, because:

exhibit useful properties such as the ability to give elasticity and plastic deformation, high strength, electrical conductivity, thermal conductivity and other characteristics.

Iron, which is the basis steel has a significant spread in the crust (5.9%) in the form of iron-containing minerals *and ores* called relatively easily extracted from the ores.

Thus, we can say that for the foreseeable period of time, steel will remain the main structural material.

1.1 Basic stages of development of steelmaking production

Metallurgy of steel as a production arose about 3,500 years ago in northern Africa (Egypt, Syria). In the development of steel production of basic units for steelmaking, production technology has undergone considerable change: *the direct reception of iron from the ore syroductnyh furnaces to obtain*

The *quality* of steel is usually divided into the following groups: steel of ordinary quality, and high quality. Differences between these groups are in the permissible content of harmful impurities (primarily sulfur and phosphorus), as well as in special requirements for the content of non-metallic inclusions. For example, in steel as sulfur and phosphorus content must not exceed 0,055-0,06% in quality steels - no more than 0,040-0,045% in high - no more than 0,020- 0,030% (in some cases sulfur and phosphorus content is permitted in very low limits: 0.010 and even 0.005%).

In chemical composition are distinguished:

1) The steel with low content of impurities, or a so-called technically pure iron, as the total content of other elements is only about 0.1%;

2) *Carbon steel* - steel not containing alloying elements (except carbon). Depending on the application, this is divided into *low-carbon* steel (0.25% C); *sredneuglerodistoj* (0.25- 0.60% C); *high-carbon* (0.6-2.0% C).

3) *Alloy steel* - steel containing, in addition to carbon and other alloying constituents, which in turn are divided into *low-alloy* steel (up to 10% PE); medium (10-20% LE) and *high-alloy steel* (more than 20%). .

For alloy steels the following letter designations of the elements are used: carbon-Y; Manganese-G; Silicon-C; Nickel-H; Tungsten - B; Molybdenum -

1. The products of oxidation of scrap iron and impurities - silicon, manganese, phosphorus, sulfur, chromium and other elements (SiO_2 , MnO , P_2O_5 , FeS , MnS , Cr_2O_3 , etc.).

2. Products fracture lining unit - with corrosion are the main liner (dolomite, magnesite) in the slag move CaO , MgO , when corrosion are acidic (acidic) - SiO_2 .

3. Impurities made the charge (sand, clay, slag, the mixing and the like), - SiO_2 , Al_2O_3 , MnS , etc.

4. Rust covering the scrap poured into the steelmaking units, - iron oxides.

5. Additional materials and oxidizing agents (limestone, lime, bauxite, fluor spar, iron and manganese ore, etc.) - CaO , Al_2O_3 , SiO_2 , FeO , Fe_2O_3 , MnO , CaF_2 , etc. . P.

Role of toxins controversial, as it may be useful as the (positive) or harmful (negative).

A positive value of the slag is its ability to absorb phosphorus (*dephosphorization*) and sulfur (*desulfurization*) from metal. Such properties are possessed only by basic slags, in which the content of basic oxides predominates, primarily CaO .

In the bottom processes, that is, in the processes carried out in open-hearth, douche and electric arc

neck. Excessive foaming leads to emissions of significant amounts of slag from any unit, which is unacceptable. In open-hearth furnaces, even moderate foaming, which does not lead to slag emissions, is undesirable, since frothy slag, having a low thermal conductivity, impairs the heat transfer from the torch to the metal, which causes lengthening of the melting and increased wear of the lining, especially the furnace vault, since a large part of the heat not absorbed by the metal is absorbed Lining, and this leads to its overheating.

Cause excessive foaming of the slag can be increased content in slag SiO_2 and P_2O_5 forming surfactant anions SiO_4^{4-} and PO_4^{3-} that enhance foam stability. A similar effect is due to the presence in the slag of very fine solids, which increase the mechanical strength of slag films (serve as a "frame").

To reduce the tendency to excessive slag foaming due to the presence therein of very small particulates, the temperature increase that ensures dissolution of solid particles in the slag. If excessive foaming is caused by an increased content of the slag SiO_2 and P_2O_5 , it is necessary to raise the basicity of slag additive into the lime bath, even better additive CaF_2 and alkali metal oxides.

General principles for setting the optimal slag smelting mode

contained therein (silicon, manganese, phosphor and others.), Particular importance in steelmaking practice have oxidation reaction. Oxygen for these reactions comes either from the atmosphere or from iron ore, or other oxidants, or bath while purging with oxygen gas.

2.1 Oxidation of Carbon

Carbon steel - is its most common impurity useful. The carbon content as a useful impurities in steel generally ranges from 1.0-1.2 to 0.05-0.10%.

Carbon in solid iron is capable of forming a supersaturated solution i.e. remain in solution in amounts greatly exceeding the solubility. As a result, some of the carbon atoms occupy sites in the crystal lattice of iron (ferrite), causing its distortion and leads to stress therein, *contributing to the strength and hardness of the iron*.

Carbon contained in the original metal stock, mainly in the iron has a decisive *positive influence on the course and the results of* oxidation refining metal in any unit. This is primarily due to the fact that during this period the carbon oxidized.

Firstly, if the carbon oxidation allocated gases CO and CO₂. This outgassing provides intensive mixing bath (metal and slag), without which the steelmaking processes in existing embodiments unrealizable. In addition, CO bubbles passing

On the residual content of manganese in the metal affects the basicity of the slag: the deeper the oxidation of manganese in the acidic process than in the core due to the fact that MnO , having basic properties in acidic slag is largely reacted with SiO_2 for example, by reacting $2 (\text{MnO}) + (\text{SiO}_2) = (\text{MnO})_2 \cdot \text{SiO}_2$. This reduces the activity of MnO in the slag and the right shift reaction.

By the end in view of increasing melting temperature (1580-1620 °C and more), and reduce the FeO content in slag (8.12% when the concentration of carbon in the metal is not less than 0.15-0.20%) values L_{Mn} reduced to 10-20 and the metal is 20-35% manganese. However, when melting steel with 0.05-0.07% C FeO content in the slag at the end of melting increases to 15-20% and over again, resulting in increased to 25-35 L_{Mn} and higher and lower residual manganese content to 15-20 %.

Providing a predetermined manganese content in the finished steel

In most cases, the residual content of manganese is significantly less than the predetermined. Specification manganese content in the finished steel is provided by introducing it into the metal in the form of a manganese-containing metal material (ferromanganese, silicomanganese, manganese metal and others.) At release in the ladle.

Advantages of the Bessemer and Thomas processes
- high performance, ease of converter device, there is no need to use fuel, low consumption of refractories and related lower than in the open-hearth and electric furnace processes, capital expenditures and expenses for redistribution.

However, both processes inherent disadvantage - an increased nitrogen content in the steel (0.010-0.025%) due to the fact that the blast air, nitrogen dissolved in the metal. For this reason, and Thomas Bessemer steel have increased brittleness and tendency to aging. For steel with a low content of nitrogen in the methods used 1950-65 purging bottom steam-oxygen mixture, and a mixture of oxygen and carbon dioxide, and a method by blowing purge oxygen enriched.

In 50-ies of XX century in a number of countries in Europe have been developed and implemented numerous variations converter process using oxygen. These processes have the common name of the oxygen converter process .

In the period from 1955 to 1975. and Thomas Bessemer process and variations thereof have been squeezed BOF process with the upper and lower feed blower.

3.2 Apparatus BOF top-blown

BOF process - a steel production of molten iron with addition of scrap in the converter with a basic lining

and blowing oxygen from above through a water-cooled tuyere.

BOF process has several advantages compared to open hearth and electric arc processes:

1) higher productivity per worker steelmaking unit (hourly output of the open-hearth furnaces and electric arc is less than 100 t / h, while the heavy converters reaches 400-500 m / h);

2) lower capital costs, is the construction of the management costs due to the simplicity of the converter devices and the ability to install in a workshop fewer melting units..;

3) less costs redistribution, which include the cost of electricity, fuel, refractories, replaceable equipment, salary, etc.;

4) the process is more convenient for the progress of smelting control automation

By using pure oxygen purge, BOF steel contains nitrogen is not more than the hearth, and the quality is not inferior OHF. Heat released by the oxidation of iron components with an excess enough to heat steel to a temperature of manufacture and allows up to 24-28% of the scrap in the charge.

Device BOF

reduce the duration of the operations, such as filling the scrap iron casting, etc.

Before starting the exercise its each melt *blending* (planning), i.e. determine the optimal data quantity terms (cost) of cast iron, scrap, slag forming materials and oxygen, providing at the end of the purge receiving metal to a target weight, temperature and concentration of carbon, phosphorus and sulfur.

Melting the course. Melting begins by loading scrap into the converter. *Filling scrap* carried out in an inclined position by means of the converter scoops, receiving such amount that the entire scrap has been submitted in one scoop, t. E. Loading implement in one portion. Uniform distribution of the scrap at the bottom of the converter is achieved by tilting in the opposite direction from the load side. Then pour from the ladle through the neck inclined converter poured liquid iron. *Pouring cast* in the desired amount, known chemical composition and temperature is carried out in one step using iron ladles suitable capacity.

After pouring cast iron Converter rotated into a vertical position. The cavity is administered converter tuyere, including oxygen supply - *purge period*. Then slag was charged with a first portion (lime with fluorspar and sometimes with the addition of ore, mill scale, pellet, bauxite). The first portion includes. 1 / 2-2 / 3 slag remaining amount

for chemical analysis and measurement of the metal temperature. In the event of a given composition or temperature of the metal is carried out corrective operations smelting:

a) with excess carbon content is held short final blow providing reception predetermined carbon content.

b) if excessively high temperature is carried out cooling the metal by introducing into it and making the shutter coolers after entering them for 3-4 minutes.

c) when there is insufficient metal temperature is carried out at an elevated position of final blow lance, or injected into the converter or ferromanganese snlikomarganets followed final blow;

g) carbon content in low produce carburizing the metal additives of ground coke or graphite on the metal stream during its release into the ladle.

After any adjustments performed in the converter, again selected metal and slag samples measured temperature.

After all necessary operations to remedy the melting converter is tilted, carrying *steel production* in the bucket through the tap hole. Release metal combined with its deoxidation-alloyed (doped ferroalloys and aluminum in a

high rate of removal of metal impurities (oxidation of carbon) with the most complete and approximately constant oxygen uptake; 2) rapid slagging; 3) no metal and slag emissions; 4) minimum formation of outstations and smoke; 5) the minimum concentration of gases in the final metal. These requirements are only possible while keeping within the prescribed limits of key parameters blowing regime, which includes the flow rate of air blast (blowing), pressure and purity of oxygen, the position (height) of the lance above the calm bath and the specific oxygen consumption.

Specific consumption of oxygen ranges from 47 to 57 m^3 / t steel, increasing with increasing content of oxidizable impurities in the iron and decreasing with increasing proportion of steel scrap in the charge, as the scrap contains less oxidizable elements than iron.

The oxygen pressure in front of the tuyere should be within certain limits. The output of Laval nozzle lance oxygen gas pressure is converted to kinetic energy. To ensure sufficient penetration of the oxygen jets into the bath and full oxygen uptake metal requires a high kinetic energy jets, however nozzle dimensions are calculated so that the jet velocity at the exit of which was 450-500 m / s . The oxygen pressure before tuyere thus should be 1.2-1.6 MPa.

temperature is 2570°C), so dissolving the necessary interaction with the oxides CaO slag phase to form a low-melting chemicals.

To accelerate the slagging to the converter at the beginning of blowing is usually sintered fluorspar (CaF_2), and enrich slag iron oxides by blowing tuyere at an elevated position, and sometimes at the expense of additives iron ore, sinter, pellets bauxite.

Slag mode. After the start of blowing in the converter slag is introduced a first portion - about $1/2$ - $2/3$ of the total. In this portion usually consists of lime and fluorspar; It is sometimes used instead of fluorspar bauxite, sinter, pellets, iron ore. Slag remaining amount is administered one or more portions during $1/3$ purge duration. Sometimes acceleration slagging of the lime (20-40%) was charged into the converter before the cast iron casting.

Total lime consumption of 5-8% by weight of the melt; it is determined by calculation so as to provide the required slag basicity. Consumption of fluorspar usually 0.15-0.3% and sometimes as high as 1%.

Furthermore fluor slag breaker primary slag, to accelerate the formation of slag blowing was started at an elevated position to saturate the slag tuyere of iron oxides.

In the course of blowing of the slag is changed: in the dissolution of lime CaO content in the slag increases, and the content of SiO_2 , MnO and FeO is reduced. Markedly reduced FeO content in the most intense period of oxidation of carbon (blowdown mid) when receiving strong development of carbon oxidation reaction due to the iron oxide slag. After purging, when the carbon in the metal is small, it begins to oxidize iron and FeO content in the slag increases.

3.8 Behavior iron and metal yield

In the BOF process, as in any other steelmaking process, depending on the melting period may as oxidation or reduction of iron. During additives solid oxidizers iron is reduced primarily carbon-metal reaction $\text{Fe}_2\text{O}_3 + 3 [\text{C}] \rightarrow 3 \text{CO} + 2 [\text{Fe}]$. During the intensive formation of slag at the beginning and end of melting (at $[\text{C}] < 0.1\%$), iron is oxidized.

If we consider the smelting in general, the BOF processes of oxidation of iron is observed, since usually sits amount of iron oxides in a solid oxidizers ($< 1\%$ of the cages) is less than their amount necessary for the formation of slag (2-3%), so inevitable loss of iron as a result of oxidation and slag in the transition typically 0.7-1.5%. If the purpose of melting the greatest possible processing scrap carried out without solid oxidizers, then the loss of iron as a result of oxidation increased to 1.5-

connection with this the beginning of the purge is obtained "cold". The drawback is considered also that its cooling effect does not affect directly the zone of maximum temperature in the converter - podfurnennoy reaction zone as scrap located under a layer of liquid iron. the time required to load the scrap and the possibility of damage to the pieces of the converter lining scrap is also a drawback of this cooler.

Iron ore as a coolant is relatively rare. When using ore excess heat consumed in its heating and reduction of iron oxides; reduced iron somewhat increases the yield of steel. The cooling effect in the ore 3.0-3.8 times the cooling effect of equal amounts of scrap; ore consumption comes up to 8%.

Compared with scrap ore as a coolant has the following advantages: it provides a high podfurnennoy cooling zone; for loading of ore is not required to stop the purge; contained in iron ore oxides accelerate the dissolution of lime in the slag, ie the slag formation speed.; oxygen presence in the ore reducing (by 10-15%) the rate of oxygen gas.

Disadvantages ore. It brings a lot of slag SiO_2 , and therefore the lime consumption increases and the amount of slag that normally causes a reduction in yield of usable. In addition, when a large flow rate of ore smelting (> 5- 6%) and its introduction in one

injected carbon can increase the scrap rate. A method often used in conjunction with oxygen feed into the upper cavity converter for afterburning of CO to CO_2 in such a combined technology proportion of steel scrap in the charge can be increased to 50% or more. Lack - complication of structure

Heating the scrap in the converter by combustion of gaseous or liquid fuel. Loaded into the converter steel scrap is preheated by means of fuel-oxygen burners, and then pour the liquid cast iron and smelting is carried out by conventional techniques. When this is achieved increase the amount of steel scrap in the charge on the 4-9% (by weight of the blend); the duration of heating at different factories is 8-18 min, 5-13 consumption of natural gas and oxygen for heating $15\text{-}20 \text{ m}^3 / \text{t}$ steel.

To increase the proportion of scrap in the charge is sometimes used *ferrosilicon*, *silicon carbides* (SiC) and *calcium* (CaC_2). These materials are loaded with scrap are oxidized with considerable thermal effect during purging. However, they are expensive and scarce, however their systemic use is futile.

Preheating of the scrap is simple converter devices (shovels and buckets) is ineffective, in that they manage to heat the scrap to only $500\text{-}600^\circ \text{C}$, and construction of special devices, improved in respect

teplotehnickom that increases capital and operating costs.

3.11 converter process with bottom blowing oxygen

The first attempts to replace the air blast in the Bessemer and Thomas processes have not yielded positive results due to lack of flushing technology, which provides high durability underbody converters. However, development of methods for bottom oxygen blowing metal continued as wide industrial application process to the upper feed blast revealed its serious drawbacks, which primarily include:

High losses of iron from the exhaust gases, slag emissions and offsets.

Incomplete and inconstant from heat to heat absorption of the blowing emogo oxygen bath.

Much additional height required for posted Nia oxygen lances.

To eliminate these drawbacks have been developed possibility of using a bottom oxygen injection. The aim was to prevent interaction of the active oxygen jets with a metal directly at the exit of the tuyere, i.e., penetrating the metal push reaction zone having a very high temperature ($> 2000^{\circ}\text{C}$) and a significant content of iron oxides, and thus causing violent rupture (erosion) of the bottom.

increased from 21 to 25-30%. The role of the heating air in the heat of the furnace is decreased, although air regenerators remain.

4.2 Apparatus OHF

Hearth furnace includes upper and lower structures (Figure 7). The upper structure of the furnace, located above the work management platform consists of a working space, heads and vertical channels. Melting (or work) space is limited to the front wall of the charging (working) windows, rear wall to the outlet, the hearth and the vault. The ends of the melting space are arranged head serving for fuel and air supply and discharge of the combustion space of the melting products. Bits are connected to the lower oven structure vertical channels. The lower structure of the furnace is disposed below the working platform management and consists of slag chambers intended for separating particles from the flue gases of entrained slag from the melting space and dust regenerative chambers and boars with changeover valves. The regenerators is carried heating of air before entering the heat for melting space they give heating smoke gases, periodically pass through the regenerators direction of movement of flue gases, air and fuel is regulated by alternately opening of certain changeover (starting) valves.

Accordingly, the refractory materials to the workspace high demands: a) high refractoriness; b) chemical stability against the effects of slag and metal the furnace gases; c) sufficient mechanical strength at high temperatures; g) good thermal stability with varying temperature.

By chemical properties applied refractories are divided into: a) acidic - Silica bricks, quartz sand; b) basic - magnesite brick, magnesite powder, dolomite; c) neutral (with properties amphoteric oxides) - chamotte, chromomagnesite, magnezitohromit, high alumina frog, forsterite.

hearth furnace

The refractory materials used in the manufacture of open-hearth furnace hearth must match the type of slag at which the melting is carried out (Figure 8). Otherwise, as a result of an energetic interaction slag refractory furnace hearth Oshlakov, i.e. it goes into the slag and furnace fails.

1 - navarka (quartz sand); 2 - navarka (powder magnesite or calcined dolomite, ground); 3 - magnesite brick; 4 - Silica brick; 5 - steel sheet; 6 - thermal insulation (porous chamotte); 7 - firebricks

Figure 8 - An apparatus acidic and basic bogie hearth furnace

The rear and front walls of the open-hearth furnace working (especially in the lower part) nearly under

the same conditions as the hearth and, as they are also in contact with the liquid metal and slag. Rear and acidic hearth furnace front wall spread of silica brick, the main hearth furnace - of magnesite.

Worn lining portions (particularly slag belt zone) are repaired after each heat (this operation is called dressing furnace) in place of the acidic corroded hearth throw sand, and the main hearth - magnesite or dolomite powder. Filling also subjected hearth end parts adjacent to the heels of the furnace: they are called sloper.

furnace roof

Code OHF substantially not in contact with the slag, so it can be produced from acidic and basic refractory materials, regardless of the type of process. The arches are made of open-hearth furnaces or heat resistance of silica-magnesia chromite bricks.

Silica brick at high temperatures (1700°C) retains a sufficient strength and an increased resistance to compression. During operation, a set of Dinas bricks welded into a monolith that can run as a self-supporting (as akrki) and ensures reliability even in case of any piece of the arch will fall. However, when heated over 1700°C Silica brick melted quickly; moreover, it greatly corrodes a melting dust consisting of iron oxides (iron silicates fusible formed).

Magnesite brick is characterized by higher fire resistance (allowable heating temperature of 1800 °C), which increases the furnace productivity. Resistance arch of magnesia-chromite bricks 2-3 times higher than that of the silica. Features of the operation code of magnesia-chromite bricks: a) bricks poorly welded together and form a monolith; b) expansion coefficient magnesia-chromite bricks higher than that of silica, whereby on heating the outer roof arch joints disclosed, but on the inner side having high compressive stress, which leads to change of the inner cover; c) an increased thermal conductivity and large leaks masonry (disclosed joints) cause higher (almost twice) heat loss from 1 m² vault area; g) the bulk density magnesite brick is 1.5 times greater than the silica. All this eliminates the possibility of the use of conventional curved arch. The Code has to do with the spacer-hanging bracket and spacers between the bricks, and this complicates and increases the cost of construction.

However, the ability to increase the temperature in the furnace roof by using magnesite as well as increase lifetime arch makes the device complicated suspension systems cost, however vaults this type are widely used.

Persistence is set magnesite 500-1000 heats (heats of silica 200-350).

the furnace head

Bits are used for fuel and air supply and discharge of the combustion space of the melting products. From that, the speed at which is introduced into the workspace air and fuel and how well the fuel and air jet are mixed, and depend from several other characteristics of the torch and the torch and the entire work depends furnace.

Heads must ensure that: 1) a good flatness of the torch across the length of the bath (to a maximum heat transfer and minimal bath - vault and walls); 2) minimal resistance during retraction of the combustion products from the workspace; 3) good mixing of fuel and air for complete combustion of the fuel in the furnace.

To satisfy the first and third requirements section outlet apertures should be small (to the air and fuel input rate are maximized); to meet the requirements of the second section, on the contrary, should be maximized. Therefore, depending on operating conditions, intermediate option selected.

slag chambers

The exhaust from the working space of the furnace flue gases pass through the head and into the vertical channels fall into slag chambers (Figure 9).

Pouring the molten pig iron is carried out by means of a removable or a stationary trough. The duration is determined by pouring cast iron organizational capabilities and usually 15-30 min. Cast iron must be poured slowly, otherwise there may be rapid oxidation of iron carbon and metal and slag emissions from the furnace.

Melting as an independent melting period begins after pouring molten iron. The main tasks of this period are metal melting and heating it above the melting point (liquidus line) at 40-60 °C and preliminary refining metal.

Establishment of optimum slag during melting mode and oxygen balance allows a major portion of the metal refining in this period, for example, in many cases provide the desired degree of dephosphorization it. Besides phosphorus, in the melting period, and other contaminants are oxidized carbon, silicon and manganese, and can also be a significant oxidation of iron. Duration melting except to the capacity and thermal capacity of the furnace depends on the melting of slag regime period, number of pig iron in the charge, the temperature of the liquid iron and the degree of heating of solid charge materials, especially scrap.

When working in batch, containing a significant amount of liquid iron (> 50%), and conducting the process in large capacity furnaces slag removal from the furnace in the melting period is an

and boils. This mixing causes heat transfer from the flame to the bath, and the temperature of the metal gradually increases.

To accelerate the slagging, sometimes at the same time to sit down and iron ore (sinter, pellets). Oxygen solid oxidant oxidizes carbon intensively, which ensures good mixing of the bath and slag formation accelerates. Polishing can successfully conduct only if the metal is sufficiently heated to the melting end. As additive of iron ore and fluxes cools bath. For the normal needs of polishing metal superheat above the melting temperature at 40-60 ° C. When said degree of superheat amount at the same time a seat materials should not exceed 2-2.5%. If the terms of dephosphorization and desulfurization is necessary to sit down more material, they are given in two divided doses, and by providing the appropriate heating bath. It should be borne in mind that 1% solid oxidizer cools bath at 20-25 ° C, lime - at 10-15 ° C, bauxite - at 15-20 ° C (in the converting process, i.e., without absorption of heat from the flame, higher cooling effect, respectively, 35-40, 15-20, 20-25 ° C). If necessary, the deep desulfurization and dephosphorization metal produce one or two additional downloading and crosstalk new slag during polishing.

Furthermore, for the normal period of polishing requires a certain stock of carbon, which is typically 0.2-0.5% and depends on the period duration (how

Basic slag during this period should be sufficient to prevent the phosphorus recovery and a sulfur removal. This is observed at the basic ~ 2.5 . But if too high, the basicity increases slag viscosity, which prevents the removal of sulfur from a normal metal and heating it.

The rate of removal of sulfur from the metal, the greater the rate of oxidation over carbon because firstly, the sulfur is partially removed along with the CO in the furnace gases from metal and slag; Secondly, the higher the rate of oxidation of the carbon, the better use of the desulfurizing capacity of the slag. Increasing the temperature of the bath during this period provides a homogeneous slag, increase in carbon oxidation rate, and this improves not only the desulfurization of metal, but its degassing.

During boiling pure normal state thanks to the bath (presence of a homogeneous and uniform slag boil) Incoming rate of hydrogen from the gas phase is reduced, and its rate of removal of CO increases in the bubbles. As a result, the hydrogen content in the metal decreases. According to numerous studies, the hydrogen content in the metal at the beginning of boiling pure typically $4-6 \text{ cm}^3 / 100 \text{ g}$, in pure boiling is reduced by $1-2 \text{ cm}^3 / 100 \text{ g}$

The duration of the boiling to clean metal degassing, including its removal peroxidation is 20-30 min. But this time it is often insufficient for heating the

practice this operation try to move completely out of the furnace into a ladle.

The total duration of the melting in open-hearth furnaces varies from 5-6 to 10-15 hours and depends on many factors furnace capacity, type of iron used (liquid or solid), its proportion in the charge, the heating system, the degree of intensification of combustion and oxidation of impurities, the degree of mechanization and furnace servicing t. d. The increase in the furnace capacity, at constant other conditions, leads to an increase in the smelting duration.

Melting liquid iron have a shorter duration than a solid, as when using liquid iron decreases the duration of loading and melting of the charge periods. With increasing iron concentration in the mixture also reduced the duration of loading and melting periods.

The use of fuel of high calorific value (fuel oil of natural gas), and its intensification combustion oxygen reduces the duration of melting of 20-25% compared to the heating furnace using a mixture of blast furnace gas and coke decrease in largest duration melting and increase productivity hearth furnaces without increasing their capacity It provides the use of oxygen injection for the direct oxidation of the metal impurities.

converter processes because, firstly, it is easier to control the current values of the carbon content and temperature, and secondly, there is an adjustable supply of heat from outside.

4.9 Indicators and perspectives of open-hearth steel production

Melting steel in open-hearth furnaces differs from conventional converter necessity for supplying heat from the outside and a high scrap rate of the charge, which results in less overall power consumption. To evaluate the process, consider results from the open-hearth material and heat balances scrapbook ore and scrap process when the melting of carbon steel.

Material balance hearth process differs from the converter, not only a smaller flow rate of pig iron, but generally of metal stock. For example, the open-hearth process scrap can be normally carried out at a flow rate of pig iron 300 kg / m, whereas for a conventional smelting converter requires at least 800 kg / m. Total consumption of metal charge in the open-hearth process typically 1125-1135 kg / t steel, whereas in the converter process is 10-15 kg / ton more.

The heat balance. In open-hearth process of drawing it is important primarily for determining the shortage of heat required for the process and fuel consumption. Specific heat deficit in the open-hearth process may vary over a very wide range:

Because of these disadvantages hearth furnace was necessary to create a new steelmaking unit, wherein the process could be carried out with more intensive blowing than in open-hearth furnaces, making maximum use of heat afterburning of CO to CO_2 . By its dimensions the machine should be such that it can be put instead of the open-hearth furnaces. This corresponds to the requirements of double-bath furnace (see. Figure 10). Workspace has two baths, each of which is provided with three tuyeres for oxygen supply and six gas-oxygen burners located in the roof of the furnace and intended for heating.

1 - lances, 2 - arched gas-oxygen burners

Figure 10 - Scheme workspace double-bath furnace apparatus

In each bath smelting is carried out with an offset of about half the duration, t. E. End of melting in a melting bath corresponds to the middle in the other. In the first bath, in which the process is completed, implemented tapping, filling a bath, the solid charge material filling and heating mainly oxidation reaction heat released from the second bath of CO to CO_2 and partially heat fuel supplied through the burner arched. At this time in the second bath is carried oxygen scavenging metal. Wherein the CO formed is partially oxidized

Warming charge (scrap) in a double-bath furnaces is predominantly oxidation reaction heat of CO to CO_2 . Warming scrap the better, the greater the duration of this period, so if the previous period - the filling is delayed, then the heating is less time. The heating temperature of the scrap, at least the upper layers thereof, should not be below the solidification of cast iron temperature (1100-1150 °C). When pouring pig iron insufficiently preheated charge occurs "zakozlenie" it, and the purge period starts abnormally: blown oxygen is poorly absorbed bath, oxidation of impurities, including carbon, are slow; advantageously oxidizes iron and the slag accumulates large amounts of iron oxides. This results, firstly, in a lengthening of the second half of melting and reducing furnace performance; secondly, it may cause ejection of slag and metal from the furnace due to possible abrupt growth of carbon with oxygen in the oxidation rate of iron oxides in the slag accumulated at the beginning of blowing, slag and metal when heated and become normal *zhidkopodvizhnost*. Overheating scrap also unacceptable, because when overheated bath accumulate a large amount of liquid iron oxides. When pouring the cast iron oxides cause rapid oxidation of iron carbon, that can also lead to release of metal and slag from the furnace. Because of the short duration (0.5-0.7 h) and charge-average *neposloynogo* warming temperature is usually 700-800 °C, which restricts the flow of scrap.

pressure in the gaseous phase Similarly for nitrogen.

Thus, when processing a metal vacuum therein is reduced content of dissolved oxygen, hydrogen, and nitrogen oxide content of nonmetallic inclusions; resulting in the release of large quantities of gas bubbles mixed metal becomes uniform, there is a "homogenization" melt.

Vacuum treatment methods were: vacuum in the ladle (with blowing an inert gas and heated), portioned and circulating evaporation, evacuation during casting.

5.3 Purging metal inert gas into the ladle

Influence of metal Purge on metal and gases on the quality of metal similarly processed vacuum. Each bubble represents a "vacuum chamber", because the partial pressures of hydrogen and nitrogen in a bubble are zero, so gases dissolved in the metal, moving into the bubble and removed along with it into the atmosphere. When purging inert gas is an intensive mixing of metal, averaging its composition; in those cases where the metal surface is covered by good slag agitation facilitates the assimilation process such as LMW; if it has a high basicity (and also low oxidation) occurs as desulfurization metal.

Technically, the purge operation of large masses of inert gases in the ladle metal is easier and cheaper than vacuum treatment, therefore, where possible, by

19 a, b) and floating (Figure 19, c). The liner or liners insulating extensions slow cooling of the top of the ingot, which contributes to the conclusion here shrinkage cavity.

Lining the feed head made of refractory bricks or refractory masses based powder with a refractory clay.

To reduce the heat-transfer surface, with extensions facilitate removal of the metal flow reduction ingot extension narrows upwardly (walls taper is 10-18%). Mass lucrative part and head trimmings, respectively the quantity of large ingots of ordinary steel is the use of such extensions 12-16 weight% sheathe ingot.

Insulating inserts are manufactured from sand with the addition of waste paper, clay and binding of asbestita with binders and other materials. Due to the low thermal conductive inserts with adapter inserts compared with lined have a smaller height and volume and their use quantity head trimmings ingots is reduced to 2-5%.

floating extension (see. Figure 19, c) is used in the casting of large ingots. Lower base such extension part into the mold; prior to the casting mold is held in extension by means of wood shims, which, after filling the metal mold is removed. The advantage of these extensions is the ability to move in the mold together with the ingot during its shrinkage, which

eliminates podvisanie ingot and formation of transverse cracks.

Pallets are used to set the through molds for casting molds from above and from the centerline at the bottom casting. A pallet is a cast iron plate 100-200 mm thick. The upper working surface of the pallet must be smooth; this ensures a tight fit to the pallet of the mold and prevents breakthrough of liquid metal under the ingot mold.

AT pallets for bottom casting (see. Figure 20) do well in the center and diverge from the open-topped rectangular channels for laying bricks siphon. If the casting mold from above is used without a bottom, the pallet making a recess in which is placed a removable liner made of steel and sometimes of refractory bricks, preventing erosion of the metal pan spray.

P

and - 4-seater; b - 60-seater

Figure 20 - for steel bottom casting Pallets

When casting the top trays are used, the size of which allows you to install one or two molds; with siphon casting of two-, four- and multi trays. Pallet consumption is 0.1-1% by weight of the cast steel.

Siphon brick prevents erosion of the pallet, center and bottom molds in the casting of molten steel. To

Classification of steel according to the degree of deoxidation

Steels according to the smelting technology, and mainly on the degree of deoxidation is divided into a relaxed, semi-killed and boiling. Killed steel is usually deoxidized with manganese, silicon and aluminum. wherein the oxygen activity is lowered so that completely stops the reaction of carbon oxidation. Casting and crystallization began to go quiet without noticeable gas evolution. Boiling steel deoxidized with manganese only partially and in the process of casting and curing in the mold is actively carbon oxidation reaction process $[G] + [C] \rightarrow CO$. Profuse bubbling CO and concomitant hydrogen and nitrogen produces boiling impression steel. Semi-killed steel according to the degree of deoxidation and, respectively, gas evolution during solidification rate is intermediate between the boiling and calm.

Features of behavior of steel in the mold determine the difference in casting technology and the structure of an ingot of a particular steel.

Ingot killed steel

The structure of the ingot killed steel shown in Figure 21.

1 - metal bridge over the sink;

subcooling decreases and new crystals hardly formed. Crystal growth continues cortical zone, wherein growing crystals main axis directed perpendicular to the wall of the mold (cooling surface). Thus, a zone of columnar crystals extending parallel to the heat sink. In large ingots with large cross section is observed deviation crystals to the head portion of the ingot (ingot to heat the center).

Length of columnar crystals increases with increasing superheat of molten steel increasing the heat removal rate from the solidified part of the ingot and increase the cross-sectional sletki; it also depends on the composition of steel (its heat conductivity).

In the central part of the ingot heat directed almost non-existent because there is low heat extraction rate, and in addition, metal is removed from the solidifying of the mold walls by the same distance. Therefore, the resulting crystals have a certain orientation is not obtained and equiaxed. Due to slow heat removal and absence of appreciable supercooling number of newly formed crystals is small, therefore, the coarse metal structure.

Education "cone precipitation" at the bottom of the ingot is usually attributed to lowering the bottom mold crystals nucleated in the liquid metal at the solidification front screen and oblom under the

influence of liquid metal flow fragile branches of acicular crystals. This lowering of the crystals is due to the difference in density of the solidified and liquid metal.

An important feature of solidifying ingot is the presence of two-phase zone between the liquid and fully solidified metal. This is the area where the growing crystals coexist axis and unhardened metal mezhsosnyh spaces. By increasing the length of time of the two-phase area increase metal stay in the two-phase state and developing stronger chemical heterogeneity.

It should be noted the presence of a solidifying ingot convective flows of the molten metal. At the solidification front flux is directed downward in the axial portion of the ingot - up. Downward movement occurs because the solidification front supercooled liquid metal and has a higher density than the rest mass. flow rate reaches 0.35 m / s ; it is the greater, the higher the superheat of molten steel, since it increases the difference in temperature and density of the metal in the bulk of the ingot and the solidification front of the ingot solidification As the quantity of liquid metal superheat, and with it the intensity of the flow is reduced. The presence of convective currents leads to increased chemical heterogeneity ingot.

Shrinkage cavity in the ingot killed steel

2 - zone cell bubbles;

3 - dense intermediate zone;

4 - secondary bubble zone;

5 - accumulation of bubbles CO;

6 - ckoplenie bubbles and shrinkage cavities;

7 - dense metal bridge

Figure 22 - The structure of the steel ingot boiling

:

outer crust thickness without bubbles can vary from 3.2 to 40 mm and depends on whether or not removed from the metal formed during its solidification CO bubbles. At the beginning of solidification of the cortical zone height overlying the metal layer and the ferrostatic pressure created by them is small, thereby forming a large number of bubbles at a sufficient CO oxidation steel. Their floating creates a stream whose intensity is sufficient for the separation of bubbles getting stuck between the axes of the growing crystals, which ensures the formation of the metal layer bespuzyristogo.

If the oxidation of the metal is small and the ferrostatic pressure due to the high casting speed rapidly increases, the bubble nucleation is difficult, they formed small and does not create a strong flow

in the liquid. Consequently, the crystals growing during solidification axis contain fewer impurities than the original steel (a process of "selective crystallization"), and the remaining liquid metal enriched with impurities.

The tendency to segregation of the various elements contained in the steel varies. The degree of phase separation is usually characterized by the following expression:

where C - maximum, minimum and mean content of the element in a particular portion of the ingot.

Distinguish two types of segregation: dendritic and zonal.

Dendritic segregation - is the heterogeneity of steel within a single crystal (dendrite): an impurity content of dendrite axes is lower than mezhosnyh volumes. The greatest propensity to exhibit dendritic segregation sulfur, phosphorus and carbon. To a lesser extent: silicon, manganese, tungsten, chromium, molybdenum and some other elements. .. The size of the dendritic phase separation, ie, the difference between the content of individual elements in the axes of the dendrites and mezhosnyh spaces reaches significant values, for example for a 3-ton ingot%: sulfur about 200, Phosphorus 150, 60 carbon, silicon 20, manganese 15.

ingot peel bloat detected congestion nonmetallic inclusions and gas bubbles resulting from the interaction of oxides contained in the cake with carbon steel. In the rolling process in place peel turn-flaw arise, requiring trimming rolled ingot surface or the surface before rolling, which complicates manufacture and leads to additional metal loss.

Intensity peel ingot growth and porosity most bloat increases at low temperatures cast steel and the casting speed, and in particular, the presence in the steel easily oxidized elements (chromium, aluminum, titanium). For reducing infestation ingot bloat resort to special measures to protect the metal surface against oxidation in the mold.

Cross-hot crack. Education outer transverse cracks - the result of the free shrinkage of the solidifying ingot obstacles. The most common fractures are caused by local hang ingot mold.

To prevent the formation of this defect is necessary to ensure a snug fit for the hot-top mold and the mold with the culling of defective walls.

Longitudinal outdoor hot crack. They occur when superheated steel casting and at higher casting speeds. Their width is 3.1 mm, length 1 m or more.

Cracks are formed as follows. As a result, shrinkage crust solidifying ingot mold and the thermal expansion gap is formed therebetween. The liquid

3) because of the small transverse dimensions of the steel ingot and high crystallization rate limited development phase separation, i.e. improved quality metal;

4) create opportunities for full mechanization and automation of casting, improve productivity and better working conditions.

In CCM, depending on the purpose, cast billet square section up to 350X350 mm round diameter 600 mm, the slabs 350 mm thick and 2600 mm wide and more complicated gauge (hollow round billet for pipe production, preform I-section, etc.).

The solidification of a continuous ingot

The approximate heat balance of a continuous ingot: mold - 16-20%; ZVO - 23-28%; Air cooling - 51-61%. In nepreryvnootlivaemom ingot can distinguish two portions of active cooling - mold and a secondary cooling zone (secondary cooling).

Metal poured into the mold in contact with its water-cooled copper walls is supercooled and solidified, forming an ingot crust desired configuration. At a distance of 200-600 mm from the top of the mold is a zone of direct contact with the crust of the ingot, wherein the maximum heat sink ($1,4-2,3 \text{ MW} / \text{m}^2$); lower peel due to shrinkage between it and the walls of the crystallizer occurs gas gap sharply reduces heat (up to $0.3-0.6 \text{ MW} / \text{m}^2$). In this zone, due to possible deformation

graphite) refrigerator, a water-cooled; secondary cooling zone 4 in the form of roller conveyors; a pulling device 5, providing a periodic elongation of the ingot; device 6 for cutting the ingot.

FROM hoist from the ladle enters (see. Figure 28) into the lined hearth, is rigidly connected to the mold through a refractory glass.

W

Figure 28 - Diagram of the horizontal continuous casting machine (the designation in the text)

it is a secondary cooling system with roller water nozzles. Next is a mechanism for periodic drawing of the ingot. The mechanism moves the bar forward by 20-50 mm, and then reverts back, after which the cycle repeats itself; during the reverse movement Bar mechanism remains stationary, or more precipitates ago. The number of cycles varies from 20 to 100 per minute.

Periodically stretch ingot mold replaces the swing used on vertical and curved machines to prevent freezes and breaks the crust of the ingot in the mold. For pulling mechanism is gas cutting and roller table with driven rollers. Horizontal caster used for casting a variety of small ingots sectional thickness of less than 150-200 mm; casting speed is 4 m / min. The main advantages of horizontal machines - low height, weight and a smaller amount

Operating experience of CCM found that by sticking to the peel ingot mold wall, and also due to warping may hang in the ingot mold. In this form discontinuities crust that not only degrades the surface of the ingot, but also can be the cause of an accident during casting. To prevent bridging ingot facilitate ingress of oil between the ingot and the mold wall, and most importantly, provide sealing (healing) ruptures crust crystallizer communicates reciprocates via mold oscillation mechanism.

Mold oscillation mechanism gives it a reciprocating motion to prevent breakage and peel ingot hang on the walls of the mold. Rotating motor or eccentric cam via a lever system provide swing frame on which is mounted a mold.

The speed of movement up and down of the mold varies in the following order: it falls down at a speed of ingot movement and upwards - with a threefold higher rate. The amplitude of oscillation varies from 1 to 40 mm, frequency - from 10 to 600 cycles per minute.

The seed is used to pull the first meters of the cast ingot. On the vertical and horizontal machines, the seed is a metal rod, and a curvilinear axis machines it is made of articulated links. The primer head is provided, in which there is a recess in the form of a "dovetail" or T-shape (see Figure 31.); seed head section corresponds to the cross section of the cast ingot. Before the start of casting the seed is

mold at a local erosion peel metal jet and gapping portions crust to the walls of the mold.

8.6 Casting and Rolling Complex

In the construction of these units utilize the principle of the combined casting and rolling processes blanks great length, i.e. two technologies - continuous casting, the cross section of which is approaching the parameters to the size of the finished product, and of direct alignment with the casting process by rolling a thin strip. Schematically this may be represented as follows: continuous casting of thin slabs - separation strips - heating, temperature adjustment - hot rolling - cooling and coiling

Casting-rolling tonkoslyabovymi complexes (with a thickness of the workpiece to 100 mm) caster began to construct early 90s and are now in their content is more than 1000 pieces.

Another embodiment of obtaining rolled sheet are at Settings continuous strip casting. Patent for direct casting a metal strip fed into the nip between two rotating rolls prepared in 1866 by Genri Bessemerom.

direct strip casting technique possesses many advantages, but above all, it excludes the conventional process operations such as casting and stripping slab reheating and hot rolling. As a result, significantly reduced capital expenditures

Metallurgy steel. The theory and technology of steel smelting. Bige. AM, Bige VA Magnitogorsk: Moscow State Technical University, 2000. - S.342-352.

Dyudkin, DA Modern technology of production of steel. / YES. Dyudkin, VV Kisilenko. M.: Heat, 2007. - 528 p.

Metals steel / Yavoysky, VI, Kryakovsky, YV, Grigoriev, VP et al -. M.: Metallurgy, 1983. - 384s.

Kudrin, VA The theory and technology of steel: Primer vuzov. M.: "Mir", OOO "Izdatel'stvo AST", 2003. - 528 p.

Chalmers, B. solidification theory. M.: Metallurgy, 1968. - 280 p.

Kolosov, MI, Smirnov Yu et al. Replacement equipment for casting steel. - Chelyabinsk, 1961. - 320C.

Production technology in modern steel converter shops / Caps, SF, old, RV, Smokty VV et al -. M.: Metallurgy, 1991. - 464s.

The development of continuous casting technology hundred there. Liakishev, NP, Shalimov, AG M.: Eliz, 2002. - 208 p.

Emelyanov, VA Thermal performance continuous casting machines. - M.: Metallurgy, 1988. - 143c.