PLASMA METALLURGY

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The rapid development of technology during the past years has led to the discovery of new, highly effective, and very intense sources of heat with a high energy concentration and a high temperature. Thanks to this, conditions were created for raising the temperature of many metallurgical processes and also for working out new methods of extracting metals from ores.

When heated to a high temperature the atoms of gases ionize; above 20,000°C the degree of ionization of most gases gradually approaches 100%. The gas is thus composed of positively charged ions and electrons. Such a medium is considered to be a new, fourth form of matter and is called a plasma. Highly ionized plasma can conduct an electric current, and, therefore, magnetic fields have an effect on it.

For a long time the study and utilization of plasmas was the monopoly of specialists working in the field of direct conversion of heat energy to electrical energy and in the field of thermonuclear reactions and rocket technology. However, certain properties of low-temperature plasma, which is easily obtained by means of special devices—plasmatrons, attracted the attention of metallurgists. There were immediately two principal directions of utilization of plasma: production of special alloys, steels, and high-melting materials, in plasma furnaces, and the development of thermal processes for ores related to obtaining metals from ores directly.

The use of units with plasma energy sources for metallurgical processes has the following advantages:

- achieving a high temperature which is easily regulated within wide limits;
- cleanness of the plasma flame, the use of which makes it possible to avoid graphite electrodes which are a source of contamination of the metal with carbon in arc furnaces;
- obtaining a plasma stream composed of any desired mixture which makes it possible to maintain any atmosphere, including a reducing atmosphere, in the furnaces;
- high rate of flow of the plasma and a very rapid heat transfer to materials being heated with relatively low losses of energy to radiation;
- high concentration of energy in a small volume.

A plasma-arc electric furnace of 0.9-ton capacity (Fig. 1) was built by the Linde Firm (USA); with respect to shape of the bath and the materials used to line the floor and furnace space, it does not differ from the ordinary electric-arc furnace with graphite electrodes. The furnace is equipped with two induction coils connected in series with the bottom electrode for uniform heating of the metal and for the diffusion of additives throughout the entire volume of the bath. Such a circuit makes it possible to get by without a special source of current for stirring the unit. The plasmatron is fed from a selenium rectifier. The working voltage is 40-60 V when argon is used as the working gas.

The electrical characteristics of the plasma-arc furnace are very stable. For example, in the plasma-arc electric furnace of 136 kg capacity and 120 kW power rating, the variation in the amount of current does not exceed ± 2% (the variation in the ordinary electric-arc furnaces reaches ± 50% during the melting period). The minor variations in current and voltage in the plasma-arc furnace are explained by the small magnitude of the voltage gradient in the arc working in an argon atmosphere (as compared with arcs burning in a medium of diatomic gases—oxygen and nitrogen or carbon monoxide) and, consequently, the greater length of the arc with the same total voltage drop.

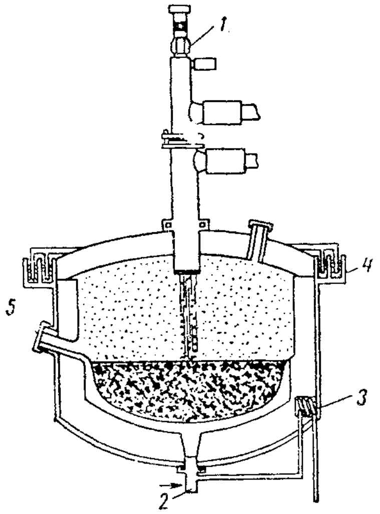

Fig. 1. Diagram of the plasma-arc electric furnace of 0.9-ton capacity: 1) plasmatron; 2) bottom electrode; 3) coil for mixing the molten metal; 4) sand trap; 5) gas-tight cover of the tap hole.

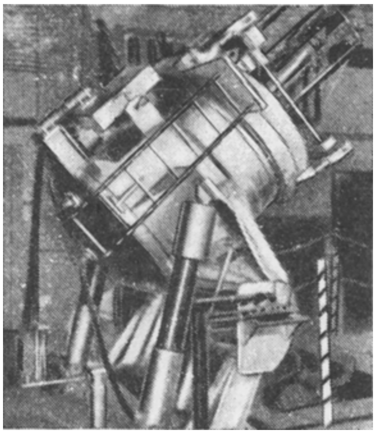

Fig. 2. Plasma-arc electric furnace of 0.9-ton capacity during tapping of a heat.

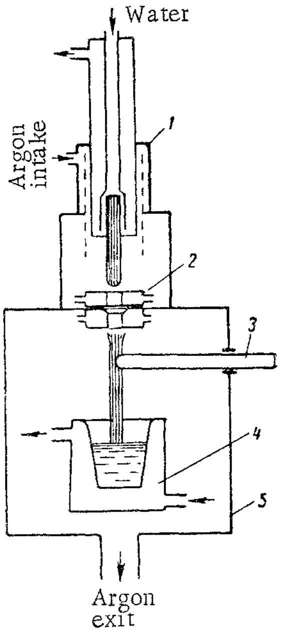

Fig. 3. Plasma melting unit with closed-bottom crystallizer: 1) plasmatron; 2) anode; 3) material being remelted; 4) crystallizer; 5) housing of the unit.

In the furnace of 0.9-ton capacity (Fig. 2) the length of the plasma flame is 910 mm. Change in its length as a result of caving of the charge has little effect on the nature of combustion of such a long arc. In the plasma-arc electric furnace the nozzle of the plasmatron is located under the arch and remains in this position during the entire heat. The danger of shorting or splashing the plasmatron with molten metal is practically excluded. The strength of the current in the plasmatron is regulated by a simple change in the reactive resistance of the transformer feeding the selenoid rectifier.

The plasma flame cuts a small hole—the "well"—through the charge. In the zone of the anode on the bottom of the well there forms a small bath of superheated molten metal through which energy is transferred to the still unmelted charge by thermal conductivity. The fraction of energy lost by the flame in radiation is small, and, therefore, the durability of the wells of the plasma furnace is not less than that of the arc furnace. The main fraction of energy received by the charge arrives by heat transfer from the zone of the anode; the bottom of the charge therefore melts first. The heat radiated by the molten metal is absorbed by the solid charge; this accelerates melting and protects the lining of the furnace from the effect of an open flame during the initial period of melting. The impossibility of blowing out the flame in the plasma-arc furnace with one plasmatron eliminates the danger of nonuniform erosion of the refractory lining of the walls of the furnace. According to the data of the Linde Firm, the lining of such a furnace of 11.3-kg capacity lasted about 200 heats.

The plasma-arc furnace of 0.9-ton capacity is attended by one steel worker who regulates the power fed to the furnace and watches the cleanness of the surface of the bath; the metal is produced in an inert atmosphere without slag.

The Linde Firm is conducting work on creating plasma furnaces with refractory linings of 2- to 90-ton capacity for production of steel and alloys in ingots. The cost of a plasma-arc furnace is about the same as that of an electric-arc furnace with graphite electrodes. Plasma furnaces of small capacity are intended mainly for obtaining high-

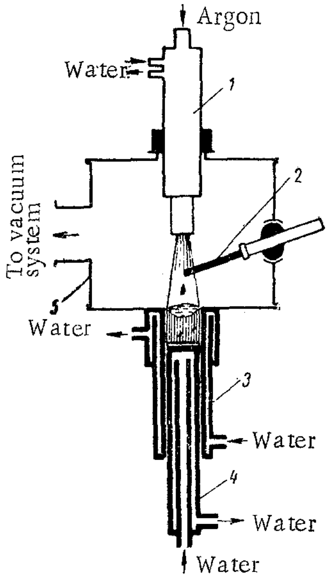

Fig. 4. Plasma melting unit with an element for withdrawal of the ingot from the crystallizer: 1) plasmatron; 2) electrode being consumed; 3) crystallizer; 4) withdrawal mechanism; 5) housing of the unit.

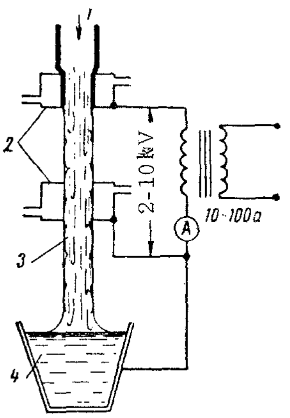

Fig. 5. Fuel-plasma burner: 1) combustion products; 2) water-cooled electrodes; 4) plasma-fuel flame; 4) material being heated.

quality casts, including casts under pressure: the furnace is tilted, and excess argon pressure is created in it, and the metal pours directly into forms fastened to the spout of the furnace. The duration of melting in plasma furnaces is 75% less than in induction furnaces, while the quality of the metal is considerably higher.

Thanks to the creation in the plasma furnace of a clean neutral atmosphere, the reducing capacity of carbon rises, while nitrogen and hydrogen are removed from the metal in the atmosphere of the furnace which is continuously being renewed. With respect to the content of gases, the steel produced in a plasma furnace is every bit as good as metal obtained from a vacuum induction furnace. The mechanical properties of metal of the plasma heat are also no worse than those of metal from a vacuum induction furnace. The presence of a neutral atmosphere and the absence of slag in the plasma furnace leads to minimum burning out of the alloys:

Alloying element	Cr	Ni	Si	Mn	V	Ti	Al	C
Coefficient of assimilation, %	100	100	100	96	95	85—90	90	86

Still more promising is the use of plasma heating for remelting steels, alloys, and high-melting compounds and metals to obtain an ingot in a copper water-cooled crystallizer. In this case the absence of a refractory lining makes it possible to raise the cleanness of the metal as compared with the plasma furnace proposed by the Linde Firm.

The use of a plasmatron heat source which permits regulation of the rate of melting and the superheating of the metal within very wide limits, favorably distinguishes the unit of this type from the vacuum electric-arc furnaces; they approximate the electron melting units which, other things being equal, are more complex and costly. An experimental plasma furnace of this type with a closed-bottom chill mold (Fig. 3) was set up in 1958 in the GDR. The temperature of the core of the plasma beam in this furnace was not less than 9000°C at a power of 15 kW and an argon input of 500 l/h. The length of the plasma flame was 30 mm with a diameter of the nozzle aperture of 5 mm. Tungsten wire was remelted in the furnace.

A plasma furnace constructed in Czechoslovakia has a crystallizer with a movable bottom (Fig. 4). In this furnace ingots 25 mm in diameter were obtained from low-carbon steel, pure iron, chromium, titanium, and from an alloy of Nimonic type. The surfaces of all the ingots with the exception of the last one were clean and bright. The iron ingots were found to be homogeneous without inner defects and with large grains of a single type. The oxygen content in the iron was reduced from 0.15 to 0.0025%, while in the low-carbon steel it was reduced from 0.030 to 0.0029%.

The great distribution of plasma melting in the USA on an industrial scale is occasioned by the low cost of argon (it has dropped by 60% in recent years).

Calculations of Czechoslovakian specialists indicate that it is already economically expedient to develop production in plasma furnaces with an argon atmosphere when the high quality of the metal obtained is considered.

In order to still further reduce the cost of plasma melting, it is possible to begin melting with cheaper gas mixtures—uncleaned argon, a mixture of argon with nitrogen or hydrogen—and finish the process by refining with cleaned argon; regeneration of spent argon can be organized.

The utilization of plasma heating in metallurgy is not limited to the creation of units for refining alloys for high-melting materials. Under conditions of metallurgical production the plasma can be used for direct conversion of ores to metal vapors which can be extracted from the plasma stream by condenstion.

The use of plasma heat opens the possibility of working out methods for reducing stable oxides of such metals as aluminum, magnesium, beryllium, and titanium which cannot be obtained by ordinary methods, since the temperature necessary to reduce these oxides is too high. The plasma stream created by the highly intense arc fed from a consumable electrode composed of oxides of metal and carbon consists of vapors of metal and carbon monoxide.

The high temperatures of the plasma stream may find extensive use as a means of intensifying ore-reduction processes, after the reactions occurring at such temperatures have been thoroughly studied and a method has been found of controlling them. However, for intensification of blast-furnace or open-hearth processes temperatures are required which are lower than those created by the plasmatrons but which exceed those obtainable by means of ordinary fuel burners.

In burners of new design (Fig. 5) energy from an arc discharge of alternating current is added to the energy obtained from burning a fuel mixture; as a result, a gas stream is obtained with a high heat content, the temperature of which reaches 3300°C. In order that the discharge be distributed through the entire volume of the flame at low working current and without appreciable wear of the electrode, the flame is made turbulent; this makes it possible to work with a voltage of the order of several thousand volts. Installation of similar fuel-plasma burners in the tuyeres of the blast-furnace would permit increasing the temperature of the blast and reducing the coke consumption. By using fuel-plasma burners in open-hearth furnaces it is possible to raise the temperature of the flame and achieve a saving in fuel and an increase in furnace productivity without resorting to feeding oxygen to the flame.

Thus, the use of plasma heating opens broad possibilities in the most dissimilar branches of metallurgy.