"Modern materials prepared with the use of levitation melting method in the magnetic fields"

dr inż. Anna Sypień

The increasing need in science and technology for a new materials possessing better mechanical, semi-conductive or optical properties makes the process of crystallization of great interest. Crystallization is the most important process determining useful properties of materials obtained by casting. Type, number and distribution of phases, as well as their geometric characteristics are determined by it. In other words, determines the structure of the cast, which directly affects the properties. That is why this paper is devoted to melting and crystallization by means of electromagnetic levitation. The advantage of the method is that, it is possible to obtain casts of a dispersed structure and to eliminate of the effect of segregation, due to short time of the crystallization during casting. [1]

If crystallization occurs during the continuous heat transfer from the casting, the metal can crystallize directionally or by volume.

- *directional crystallization* is defined as continuous movement of solid / liquid interface from one end of the form to another.
- *crystallization by volume* also called crystallization of the equiaxial grains, very often occurs when the liquid metal crystallizes in the classical casting.

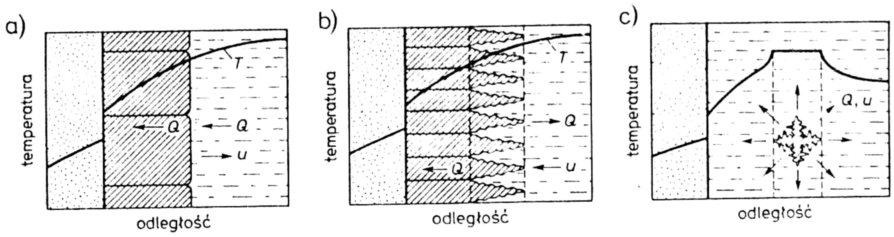


Fig. 1. Temperature field direction of the crystal growth and the heat flux during directional a and b, and volume crystallization c [1].

A characteristic feature of the directional crystallization of metals (Fig. 1a) and alloys (Fig. 1.b) is growth of the crystals from the surface of the mould, which is place of heat release and movement of solid / liquid interface in the direction opposite to the heat dissipation. In the case of volume crystallization of metals and alloys (Fig. 1.c), the crystals grow in the direction of heat dissipation from the melts, that is now the outlet for the heat of the crystal. Generally speaking, the process of the rapid crystallization means the presence of high speed cooling or high undercooling, in order to obtain a high speed movement of the crystallization front ($u>1$ cm/s)[2]. The type of the process, the cooling rate, as well as the type of the material, determines the type of nucleation and growth of the solid phases. A number of metastable phases can form in the material, which may have quasi-crystalline structures of different types (dendrites and eutectics).

Rapid solidification process usually occurs in two cases:

1. Undercooling of the liquid, which can be achieved by cooling below its freezing point with subsequent rapid solidification of the whole volume of liquid in the absence of heterogeneous nucleus (during levitation melting).
2. Under conditions of rapid movement of the temperature field, what happens for example, during laser melting or welding when concentrated heat sources such as laser or electron beam are used.

The process of rapid crystallization enables to obtain materials with better properties, improved due to: dispersion of the dendrites or eutectic microstructure, elimination of the effect of segregation, formation of the solid phases of due to extended solubility of the components or formation of the metastable phases, change of the phase morphology [3].

Modern technology requires metallic materials with high performance. To achieve such properties is necessary to find ways of materials melting securing high purity.

One of the main problems is contamination of the liquid metal by the material of crucible or furnace atmosphere, especially when we are dealing with refractory and reactive metals, specifically reacting with the crucible material (substrate). Because of that the wide application in metallurgy found methods of non-crucible electromagnetic levitation melting.

On the other hand the levitation methods make possible to obtain castings of particulate structure and to eliminate segregation while preserving the high purity of alloys. The use of the vacuum arc melting and water-cooled copper crucible does not provide a uniform composition and structure of the alloy due to some strong temperature gradients.

The principle of electromagnetic levitation melting of metals

The conductor placed in the high frequency electromagnetic field behaves as a diamagnetic material in the permanent magnetic field. It is repelled to the space where the field is weak. This is due to the interaction between the external field and the induced internal currents in the conductor – giving the net force acting in the molten metal. At the same time the eddy current heats and melts the sample (Fig. 1). For the phenomenon of levitation it is necessary to create gradient and the value of magnetic component of the field to compensate the weight of metal and to keep it in the stable position by magnetic forces. For the formation of the field with a particular geometry appropriately shaped coil, usually from copper tube and intensively water cooled are designed. The coil is powered by high-frequency generator, with an output of at least few kilowatts. Then in the central part of the coil the field is weakest, and the metal is pushed to this zone occupying more or less stable position.

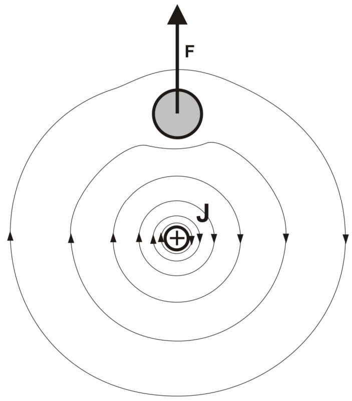
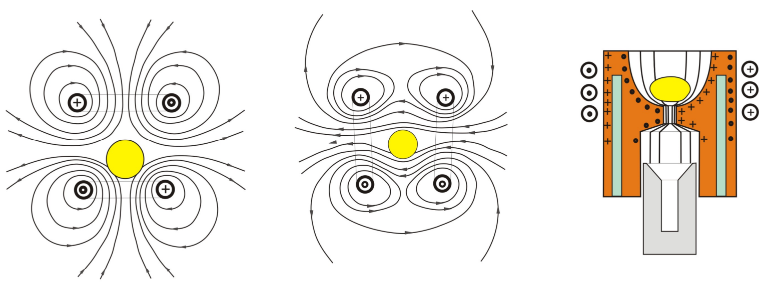


Fig. 1. The interaction between electromagnetic field and the conductor placed in it.

In literature, one may find lot of construction schemes of coils. Broadly they can be divided into three main groups:

1. double-part coils cylindrical or conical with vertical axis of symmetry,
2. the “boat-type” coil"[4],
3. the multisection copper crucible for CCLM (Cold Crucible Levitation Melting)[5].

The principles of their construction are shown in Figure 2.



1 2 3

Fig. 2. The three basic schemes of the coil construction for levitation and melting of metals: 1 – double-part coil cylindrical or conical with vertical axis of symmetry, 2 – the “boat-type” coil [4], 3 – the multisection copper crucible for CCLM [5].

The proper values of obtained field, the shape and size of coils makes a relatively small mass of metal to levitate in the electromagnetic field. The mass usually does not exceed a few grams, what is sufficient in many types of laboratory tests. Larger quantities of metal, some kilograms of ingots may be melted in the actuators listed in Section 3, when multiple-hub for the "levitation melting in cold crucible " is used. In this case, however, very large power of generators, of several hundred kilowatts is required [6].

From physic of melting results that the stability of metal not only depends on the power supply (including current frequency), but also on in a large extent on the physical and chemical properties of the metal itself (density, electrical conductivity, coefficient of heat emissivity, surface tension at a given temperature) and the surrounding gas phase. This often leads to a significant overheating of the metal or alloy above the melting point. This may caused deteriorating of the metal stability both of the shape of the droplet and of the location in coils, until falling out of the area of the magnetic field. Proper design and selection of coils parameters should allow to obtain a sufficiently stable levitation of larger quantities of metal, and obtaining from them useful micro-cast.

A review of the literature and the author own experience shows that the method of levitation melting can be widely used for the preparation of alloys, and to the investigations of processes of physical and chemical character using them. The main advantage of this method is lack of a ceramic crucible, what protects the molten metal from contamination by side reactions. In addition, molten metal is then vigorously mixed, and therefore homogeneity in composition is obtained. After dropping the metal to the mould it can be quickly frozen. When using other techniques without the use of ceramic crucibles, e.g. arc melting witch a water-cooled copper crucible, the mixing is not good and as a result of sharp temperature gradients, the structure and composition of the alloy may be heterogeneous, and requires, further repeated melting and subsequent homogenization. Because of the difficulties meet in the case of melting of certain metals and alloys, levitation melting should not be considered as a universal method, but only as a complementary tool in the field of metallurgy [7].

To develop the advantages of levitation melting methods, the laboratory was created in IMMS PAS with several levitation furnaces for the preparation of the small quantities of various metal, summarized beloved.

1. The furnace for the electromagnetic levitation of metals, with the coil placed inside the furnace.

Applications: Melting and casting of metal alloys up to 1 cm^3, with homogenization and rapid freezing by pouring to the copper mould.

2. Induction furnace for melting using CCLM type cold crucible with diameter of 44 mm.

Application: preparation of metal alloys, mainly mainly based on Fe, Ni and Co, in an amount up to about 3 cm^3. As a rule, metal solidifies in the water cooled cold crucible. It is also possible to cast the metal to the mould by central hole of the crucible, while the surface tension of metal is low compared to its density.

3. Induction furnace for melting using CCLM type cold crucible with diameter of 25 mm.

Application: Preparation of metal alloys (similar to the previous case) in an amount to 1.7 cm^3. In this case the metal freezes in the crucible. The furnace is designed to obtain ready-made samples or charge for remelting in the vacuum induction furnace.

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