The influence of melt state on atomization process and quality of powders on iron and nickel base

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Abstract. The analysis of the results of physical and chemical properties and structure investigation in liquid multicomponent steels and alloys indicates that after melting their state is generally not in equilibrium. Heating to the critical temperatures helps the system to transform into the equilibrium state or the state close to it. Melt preparing before atomization affects the process of liquid metal dispersion and helps to improve the structure and properties of the powder. The optimum melt preparing technology before atomization leads to formation the dispersion dendritic structure, optimum morphology, quantity and size of primary and eutectic phases in the powders particles and increase in properties.

1. Introduction

Recently there has been a lot of interest in atomization of molten metals in connection with the production of metal powders. It is a process in which a molten metal stream is disintegrated into large number of droplets of various sizes by impingement of high velocity fluids like air, nitrogen, argon, water steam. The droplets of freezing liquid constitute the metal powder. Some characteristics of the powders such as mean particle size, particle size distribution are important for reasons related with the control and the production efficiency. These characteristics, however, depend on a large number of parameters including thermophysical properties of the liquid to be atomized and of the atomizing medium, operating variables like liquid temperature, liquid feed rate, of atomizing medium pressure and feed rate, and the design parameters such as nozzle design, and the design of the atomizer which in turn determines the jet geometry [1-3]. For an effective and meaningful process control it is essential that the affect of these parameters and variables on the process is quantitatively known.

The investigation of melts structure and properties shows [4] that they, as any other thermodynamic systems, should be divided in two groups:

- nonequilibrium, i.e. preserving some features of structure of initial solid phase for some time;
- equilibrium, which structure and properties are determined not by pre-history but by composition and external parameters.

Both groups are connected with the initial crystal state. The first group is connected by the means of nonequilibrium elements of its state. The second one is connected by the interatomic interaction and by the local order.

At present, in the majority of cases the solidification of industrial metal takes place from the nonequilibrium state that intensifies chemical and structural inhomogeneities in the solid metal deteriorates the service properties and leads to significant variations in its quality from melt to melt.
Nevertheless it was shown that one of the most important ways to decrease the structural and chemical inhomogeneities of a steel ingot and to make improvements in the quality lies in obtaining the equilibrium melt of maximum homogeneity before the crystallization.

The creation of the new melting technique named “melt preparing technology” is based on combined analysis the data on the structure and properties of liquid steels and alloys as well as the revelation of the types of structural rearrangements in the melt and their influence on the process of structure formation during the solidification.

Some results of the “melt preparing technology” application during the production of more than 70 types of steels and alloys of different classes show the following [4]:

- the depth and the volume of the shrinkage hole is decreased by 6-50%;
- the zone of ingot columnar structure is decreased;
- the metal output is increased by 5-7%;
- the dispersity of the dendritic structure is increased by 10-15% and it's homogeneity is improved;
- the eutectic carbides quality is decreased by 15-30% for different steels and alloys;
- the dendritic segregation of alloying elements is decreased;
- the density of cast metal is increased.

The cast metal structure modifications due to the formation of equilibrium melt affect its service properties. The ductility of steels is increased by 20-40%, especially at the hot plastic deformation temperatures. Its temperature interval is expanded. The elastic steel properties are increased by 30% and temperature conductivity - by 20%. For stainless steels the growth of their creep life by 20-50% and corrosion resistance by a factor of 3-4 was established. The cutting properties of tools made of M2 type steel increase by 30-40%. The service properties of the other alloys and materials are improved.

2. The experiment
To the obtain information about the structure and properties of some liquid steels and alloys, the following physical and chemical properties were measured within the temperature range of 1200 - 2100 K: electroconductivity, viscosity, density, surface tension.

The results of experiments were used to propose the melting regime before the atomization. The experiments have been carried out both in the laboratory condition and in the industrial ones. For the comparison these powders were produced by the traditional technology. It is necessary to note, that during the atomization all the parameters of process were constant.

For atomized powders the particle size, shape, purity and structure of the particles were studied by traditional experimental procedure.

3. Results and discussion

3.1. Properties of liquid metal
It was established that for each steel the plots of temperature dependences of properties have their own characteristic form. By analyzing the shape of the polyterm, it is possible to determine the main features (figure1). It is a hysteresis (deviation between the heating and cooling branches) and the discontinuities (jumps in the temperature derivatives of the properties). The presence of a hysteresis indicates the irreversibility occurring during the heating process and the disappearance of nonequilibrium formations inherited from the solid state. The discontinuities suggest nonmonotonic behaviour and sometimes jumps occur in the transition process of the system to equilibrium.

The conversion of the melt to the equilibrium state takes place during the heating to certain temperatures, called the critical temperatures \( t_c \). Upon attaining them the energy of the thermal motion of the particles in the melt becomes comparable to the bond-breaking energy of the strongest interatomic interactions in the nonequilibrium atomic clusters, i.e. to the activation energy of migration processes of the most strongly bounded particles.
Since the transition process of the system to equilibrium state as a result of heating occurs nonmonotonically and becomes much faster on reaching the critical temperatures, heating the metal to these temperatures is the main feature of the new progressive technology. During cooling the liquid metal, prepared by this way, its initial (nonequilibrium) structure does not restored.

Thus, before solidification the structure of the melt may be in different states: equilibrium and nonequilibrium. The melt state influences on its physical and chemical properties before solidification and gives the opportunity to control the forming structure and properties of the solidified metal. It is necessary to note, that the equilibrium melt has as a rule the greater surface tension and viscosity and lower density before and under the atomization.

3.2. Structure and properties of the powders
Comparison of the size and size distribution of the powders that was atomized from different melts states shows the following:

- if the melt was in equilibrium state before atomization, the sizes of powders particles decrease (figure 2). Usually mean powder size is decreased by a factor of 2-2.5. So, the increasing value of $\nu$ and $\gamma$ due to formation of equilibrium melt, leads to decreasing the mean powder size under atomization;

- the shape of the particles becomes closer to an ideal sphere, its surface becomes free from satellite drops. Nichiporenko [5] in his works showed that shape formation of solid particles is determined by physical and chemical properties of liquid metals, temperatures of atomization and solidification of melts. If the melt was transformed to the equilibrium state before atomization, the lifetime of liquid droplets is increased due to the increase of supercooling and the absence of nucleus of crystallization. In consequence powders particles have the shape of sphere, their structure becomes more dispersed and modified;

- the dry density of the particles increases by 8-10%;

- the oxygen content and inside porosity decrease. The special investigations show that the melt condition has influence not only the oxygen content but its form of existence. In particular, for powders of Fe-C-Si-Cr-Ti composition it was shown that after the atomization of equilibrium liquid alloy oxygen is connected in the simple iron oxide, as a rule. Under atomization of nonequilibrium melt the greater part of oxygen is connected in the strong oxides of titanium and chromium;

- the dendritic cell sizes in the structure of the powders particles decreases by 15-20%. This dependence is observed for the powders with different diameters of particles;

![Figure 1. Effect of temperature on the kinematic viscosity (a) and surface tension (b) of some Ni-based alloy, used for powders production: ●- heating; ○- cooling.](image-url)
- the amount of the primary phase in powders structure decreases. The sizes of primary and eutectic phases are pounded. It was established for cast iron powders that the transition from stable to metastable mechanism of solidification took place at some cooling rate. When the atomization was done for heat-treated melt, the decrease of this critical cooling rate was found;

- the increase of particle size leads to the decrease of the hardness of powders. However, the absent of polymorphic transformation in solid state makes this effect weaker.

The modifications of the structure and properties of powders due to formation from equilibrium melt affects the service properties of powders and powder parts. Improvement of the quality of powders of high speed tool steels helps to improve the service properties of sintered metals. The density of the warmed up steel increases by 3-5%, the size of oxide inclusions decreases by a factor of 5-8, and the dispersion as well as the amount of carbides increases in its structure. The durability of a shaping tool increases by a factor of 1,5.

4. Summary
1. The analysis of the results of physical and chemical properties and structure investigations of liquid multicomponent steels and alloys indicate that after melting their state is generally not in equilibrium. For each melt there are temperatures at which the structure changes especially intensively. Heating to these critical temperatures helps the system to transform into the equilibrium state or state close to it.

2. The preparation of a melt before atomization affects the process of liquid metal dispersion and helps to improve the structure and properties of powders. The optimum melt preparing technology before atomization leads to the increase of the dispersion in the dendritic structure, changes in the morphology, quantity and size of primary and eutectic phases of the powders particles. As a rule this is accompanied by the increase of the powders output technological and work properties of powders and powder parts.

3. The melt preparation before atomization leads not only to improvement but also to stabilization of the structure and properties of the metal from serial to serial.

5. References
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