

Influence of Melt State on the Properties of Nickel-based Powders for Wear-Resistant Coat

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Abstract. The influence of time-temperature treatment on properties of the PG-SR-type alloys in cast condition, in produced powders and coatings is studied in this work. The temperature dependence of physical properties were obtained. These results and the comparative metallographic analysis have allowed offering the mode for time-temperature treatment of the liquid PG-SR-type alloys. Use of the time-temperature treatment when producing metal powders and coatings are as follows: the dispersibility of powders increases; the yield of powder fractions used for applying coatings increases; the powder porosity and oxidation decreases; oxidation resistance in various media increases; corrosion-, heat-, and wear resistance increases.

1. Introduction

The PG-SR-type nickel-based alloys containing chromium, boron and carbon for applying wear- and corrosion-resistant coatings, thanks to their chemical composition, have a great variety of simple phases and complex structures, which are usually far from equilibrium and micro-homogeneous state. [1,2].

Attempts to stabilize or improve service properties are normally associated only with additional charging of such expensive materials as tungsten, titanium and others to the PG-SR-type matrix alloys [3-5]. Such an approach allows sometimes solving private tasks, but can not be scientifically justified and is of low commercial effectiveness.

Numerous experimental works on physical properties and structure of liquid steel and alloys show that in most cases after melting metal is in non-equilibrium state [6-8]. And depending on the choice of charge materials, heating conditions, time of dwelling metal in liquid state the deviation degree from equilibrium may be different.

One of the methods of forming equilibrium and homogenous structure of the melt is its time-temperature treatment in smelting process based on a study of the melt structure formation processes and an analysis of the relationship of the structure in liquid and solid states [7].

In this regard, the influence of time-temperature treatment on properties of the PG-SR-type alloys in cast condition, in produced powders and coatings is studied in this work.

2. Materials and methods

Optimal temperature and time parameters for melting process were searched for and proved on the basis of the study results of temperature dependence of melts physical properties. The kinematic viscosity (ν) was measured by a method of torsional oscillations of a crucible with a melt, the surface tension (σ) and density (d) were measured by a sessile drop method, the specific electrical resistivity



(ρ) by a non-contact method in a twisted magnetic field, the magnetic susceptibility (χ) was measured by the Faraday method. All studies were performed in an inert atmosphere. Before conducting the experimental test the system, the main elements of which are a metal chamber with an electric resistance furnace and a measuring cell with a test sample, was preliminary vacuumed to reach the pressure of $1.33 \cdot 10^{-3}$ Pa, was flushed out and filled with purified helium to reach the pressure of $1.11 \cdot 10^5$ Pa. The temperature in all plants was measured with the tungsten-rhenium thermocouple BP 5/20, hot junction of which was in the vicinity of the test sample.

The PG-SR-type nickel-based alloys used for applying wear- and corrosion-resistant coatings were selected to conduct the study. The chemical composition of the studied alloys is shown in the table 1.

Table 1. Steel composition of PG-SR-type alloys.

Grade	Content of elements in %wt					
	Ni	C	Cr	Si	B	Fe
PG-SR1	Basic	0.2-0.4	12-14	2.0-2.8	1.2-1.8	<5
PG-SR2	Basic	0.35-0.60	14-16	2.8-3.5	1.8-2.3	<5
PG-SR3	Basic	0.60-0.90	15-17	2.7-3.7	2.3-3.0	<5
PG-SR4	Basic	0.80-1.20	16-18	3.8-4.5	3.1-4.0	<5

3. Results and discussion

The study results of temperature dependence of physical properties of the PG-SR1 alloy are given in figure 1.

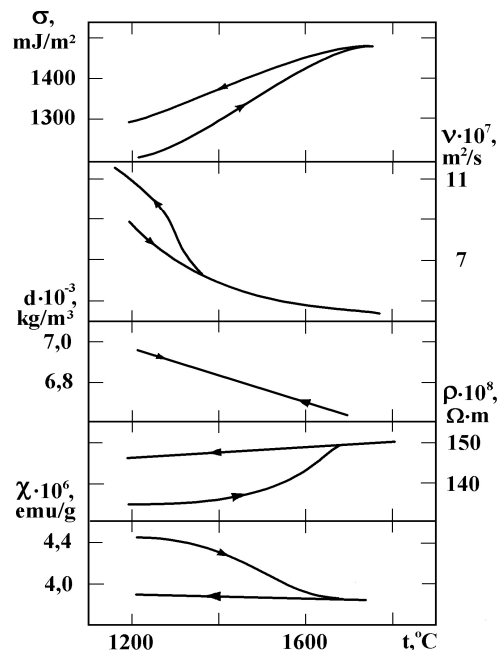


Figure 1. Temperature dependences of physical properties of the PG-SR1 alloy during heating and cooling.

The obtained dependencies $\nu(t)$ of all the studied alloys of the PG-SR group allowed to mark out two structural regions of a melt. Low temperature area is characterized by a sharp change in viscosity from extremely high to low inherent in metallic liquids, i.e. this is a region of a heterophase state of

the melt. Temperature values separating these regions depend on the chemical composition of the alloy. Improving an alloying degree increases the marginal temperature from 1230 to 1470°C.

In high-temperature regions, i.e. above the marginal temperature, there are changes in the nature of heating and cooling polytherms v and their hysteresis (Figure 1), which can be achieved only when heating is performed above the critical temperature (t_f).

According to the nature of the polytherm property change the main parameters of the time-temperature treatment (TTT) were defined. It involves heating of the liquid metal above the critical temperature, dwelling over a certain period of time and cooling up to the casting temperature or up to the dispersing temperature at a given speed.

The structure of cast samples proved to be dendritic. However, in samples, that were cast according to the technology existing at the plant, strong development of first-order dendrites was observed. This was eliminated by introducing the TTT.

A quantitative metallographic analysis of the PG-SR2 alloy has showed that using the TTT can reduce the overall number of strengthening phases (table 2), eliminate the visible appearance of primary needle shaped carbides and reduce the number of eutectic carbides almost 1.8 -2 times. The structure of strengthening phases also changes. It forms a continuous and rigid lattice in samples cast according to the plant technology. The time-temperature treatment allowed for the lattice transformation, its division into individual fragments and the emergence of regions spherulitic eutectic. The latter shows that the forms of primary crystallization centers have changed in alloys.

Table 2. Structure characteristics of cast samples of the PG-SR2 alloy.

Smelting technology	Dendritic Cell parameters, μm	Number of strengthening phases, volume %	Micro-hardness of the γ -phase, hPa	Number of spherulite-like eutectics, volume %	Wear-resistance, times
Plant	12.4	32	84	0	1
Under the TTT of the alloy	11.9	23	101	1.80	1.8

Discontinuity of the silicate-boron-carbide lattice and appearance of spherulite-like formations in alloys of the eutectic type contributes to enhancing their plasticity [6-8]. Introduction of the technology using the TTT of the melt has led to a reduction in the size and number of slip lines, formation of units concentrated in the fields of spherulite eutectic formation inherent in ductile fracture [7]. In general, the outlined structural changes enhance plasticity of the PG-SR-type alloys.

The TTT of the melt contributes to improving the components solubility in a nickel matrix and the uniform elements distribution by metal volume and between phases. Also the alloying degree of γ -solid solution increases, as evidenced by the increase in micro-hardness of the alloy matrix (table 2).

Based on the study results of the temperature dependence of physical properties of a melt and interrelationships of liquid and solid states the melting conditions before dispersing have been offered, experimental melt heats have been carried out and a comparative study of properties of the manufactured powder and coatings has been performed.

The following service properties were studied: dispersion, oxygen content, porosity, micro-hardness, heat resistance and structure of powders manufactured according to the plant technology and experimental technology.

The grain-size analysis showed that the TTT increased dispersion of powders. With this the particle yield with the size of less than 150 μm , that is the most suitable for applying coatings, has increased 3-6 times, and the average particle size of powders decreased 1.8 -2.0 times.

Preparation of the melt for dispersing under TTT modes significantly reduces the oxygen content in powders as well as lowers their porosity.

Powders with particle sizes from +0.1 to 0.2 mm were used for applying coatings by thermal spraying on cold steel backplate followed by fusion of the working surface in acetylene-oxygen flame. After fusion the coatings made of PG-SR-type self-fluxing alloys were polished with silicon-carbide grinding tools.

If powders were manufactured under the TTT of the melt, the non-fused powder coatings have had lower porosity. After fusion this trend picks up. With this, the porosity of powder coatings, manufactured according to the existing plant technology, equals to 0.41% and according to the experimental technology equals to 0.18%.

Coatings made of experimental powders enjoy hardness increased by 15% that is connected not only with the reduction in their porosity, but also with great content of fine boron carbide particles in their structure.

Coatings manufacturing technology allows for materials heating in the air in the temperature range from 75°C to 1300°C. Hence the study of the kinetics of the samples oxidation was carried out in this temperature range. Experimental data allowed to make the conclusion that the PG-SR1 cast alloy that was obtained from the equilibrium and homogenous state of the melt before hardening is marked by the 35-55% lower speed of oxidation. In terms of oxidation resistance the experimental technology contributes to approximation of this alloy to the samples of more doped PG-SR4 alloy manufactured in accordance with the plant smelting technology (figure 2).

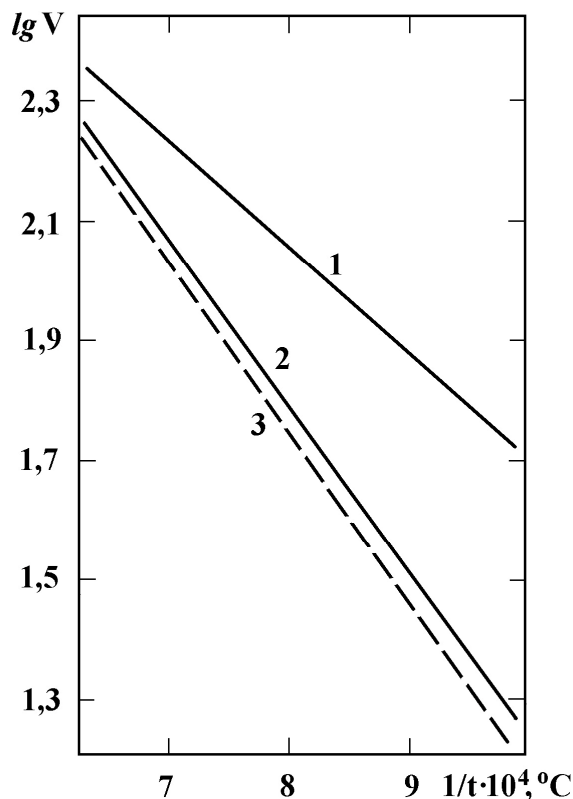


Figure 2. The dependence of the logarithm of the air oxidation speed of PG-SR1 (1 and 2) alloy samples and PG-SR4 (3) alloy on the return heating temperature. Temperature range of the experiment is from 750 to 1300°C; 1,3 is a smelting technology existing at the plant; 2 is a technology using the TTT of the melt.

The most important service property of PG-SR- type alloys is wear-resistance. Changes in weight of a reference standard and a sample after 10 test cycles were compared to quantify the wear resistance index. The time-temperature treatment of the melt of the constant chemical composition helped to increase the wear resistance of the PG-SR1 alloy 1.8 times and PG-SR2 - 1.6 times.

4. Conclusion

The PG-SR-type alloys were found out to be in a non-equilibrium and micro-inhomogeneous state after melting. Measurements of the temperature dependence of physical properties allowed to determine the temperature range when the melt progresses to the equilibrium state. These results and the comparative metallographic analysis have allowed offering the mode for time-temperature treatment of the liquid PG-SR-type alloys.

Experimental data on the high efficiency of the smelting technology using the time-temperature treatment when producing metal powders and coatings are as follows: the dispersibility of powders increases; the yield of powder fractions used for applying coatings increases; the powder porosity and oxidation decreases; oxidation resistance in various media increases; corrosion-, heat-, and wear resistance increases.

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