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Analysis of thermal peculiarities of alloying with special properties

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Abstract

In this paper an algorithm solving the problem of high-speed thermal cooling of molten metal and alloys in order to form an amorphous structure is developed. The rate of alloy cooling was calculated by numerical solution of the problem of heat transfer between melt thin layer and solid metal plate with high heat conductivity. Basing on the results of field research an amorphous structure of the deposited metal was obtained; conditions for this technology realization were defined.

Keywords: *quenching; amorphous structure; cooling rate; surfacing*

Introduction. Alloys with amorphous structure have high hardness and strength, which vary depending on the chemical composition of an alloy. For alloys based on iron subgroup elements (Fe, Co, Ni) hardness according to HV may reach the values > 1000. High strength and wear-resistance make amorphous metals ideal materials for use in heat power engineering, in particular for hardening turbine blades, spindles, which are under dynamic loads during operation.

Amorphous structure cannot be obtained without super-high cooling rates in the process of structure formation. Thus, the study of thermophysical processes during formation of amorphous structure will allow to determine the most optimal technology of amorphous metal

layer and the conditions for realization of this technology.
In the earlier studies a variety of realization ways of this principle was proposed. There are discrete and continuous methods for obtaining amorphous metal [1]. The methods of drops catapulting on the cold plate, spraying jets of gas or liquid, ultra-fast cooling from the gas medium, etc. are known [2-4]. The usage of these methods allows obtaining a stripe with 15 mm width and 30 ... 40 mm thickness, wire and powders, but for obtaining a surface layer with an amorphous structure these methods are unappropriated. In the technology of quenching from the liquid state the layer of melted metal contacts with the surface of massive body (a body-fridge) and is cooled by means of heat removal in its internal layers. In this case the processes of formation of the primary alloys structure, as well as subsequent solid phase transformations are accompanied with formation of different structural types of metastable states (amorphous structure), analysis of which this paper is devoted to. For obtaining the amorphous structure of the metal the surfacing of samples from low-alloy steel presented in the Figure 1 was performed.
The structure of welding metal is determined by the cooling conditions which affect the processes of metal solidification and diffusion processes. Therefore, on the experimental installation there available a system of forced cooling of the coating surface of melt.
To study the regularities of structuring and dependence of its effect on the mechanical, electrical and other properties of the metal after surfacing, metallophysical researches were performed, in result of which it was established that deposited layer has a crystal structure, mainly ferritic one.
When the layer is cooling down (Figure 1), the crystals grow in the direction opposite to heat removal, deep into the liquid bath and the metal acquires a columnar structure. Crystallite consists of several dendrites, which have a general directionality, and may have different degree of branching. Under higher cooling rates, in the welded metal of these steels, besides ferrite and pearlite, there also may be present martensite, bainite and residual austenite. Martensite in such steels is distinguished as structureless and bainite is represented as a ferrite-carbide mixture of high dispersion. The amount of structural components is changing depending on the temperature cycle of surfacing. As the structure of analyzed samples, shown in the Figure 1, has a crystalline structure, one may conclude that without usage of technological process while surfacing, which is aimed to increase of cooling rate of the melt, with a view to rapid heat removal, to receive amorphous structure of welded metal is impossible.

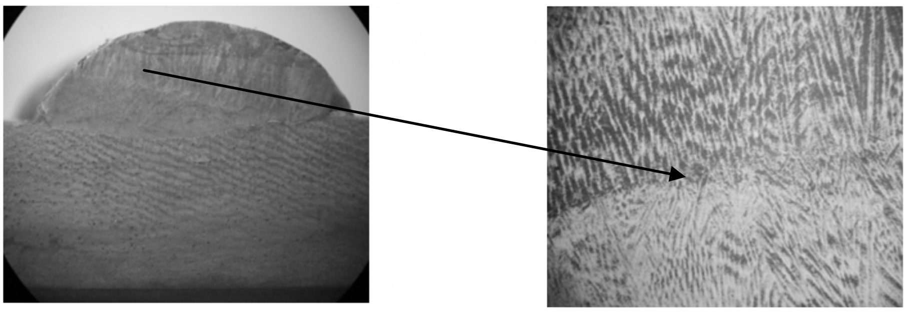


Figure 1 Structure of the deposited metal

It is known that while surfacing cooling rate of the melt directly depends on the heat input of the process, with decrease of heat input rate, cooling increases. Surfacing rate V_s is significant parameter of surfacing regime, which influences the heat input. With increase of surfacing rate, the heat input decreases, which in its turn increases the speed of cooling process [5]. Surfacing of subsequent samples was carried out with increasing surfacing rate V_s, 16...18 m/h, the other mode parameters were left unchanged. The results of metallophysical studies are presented in the Figure 2, whence it follows that the increase surfacing rate has led to grain refinement and improvement of metal structure.

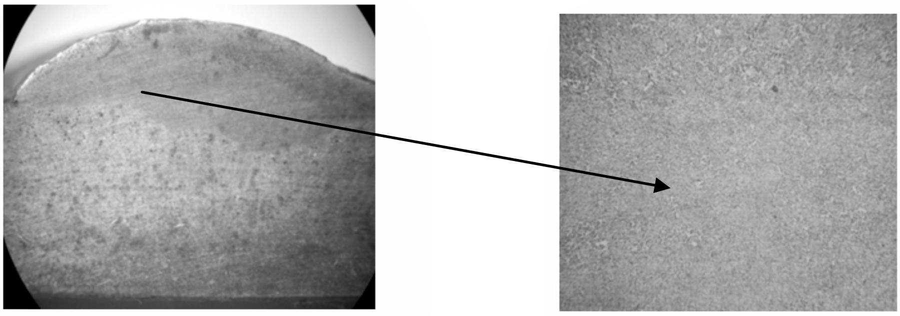


Figure 2 Structure of the deposited metal

To produce the amorphous structure of deposited metal one should apply technique that will ensure rapid heat removal from the place of surfacing, provide a high cooling rate 10^4 ... 10^5 K/s and above. In order to remove the heat from surfacing place rapidly, the constructive device for cooling the melt was made on surfacing equipment; this allowed to achieve required cooling rate. With increasing the rate of heat removal metallophysical studies fixed the amorphous structure of deposited metal (figure 3).

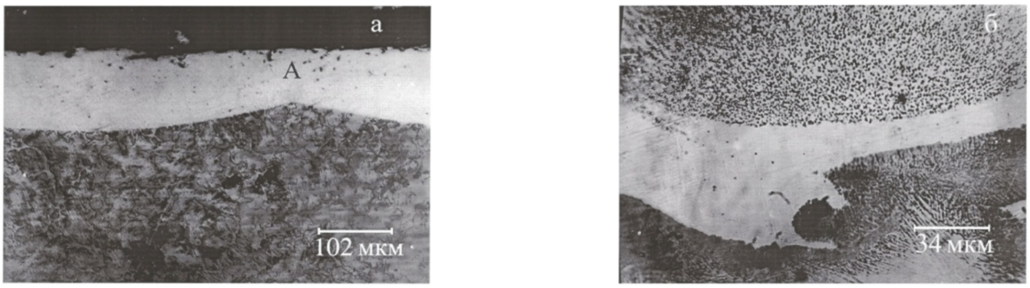


Figure 3 Amorphous structure of the deposited metal

The desired structure of deposited metal may be obtained only under the conditions of interaction of such factors as cooling rate, melt layer thickness and deposited metal mass. The rate of alloys cooling was calculated by numerical solution of the problem of heat exchange between melt thin layer and a solid metal plate with high heat conductivity. While cooling of the smelted layer of metal, the temperature of upper layers of the solid mass increases and corresponds to the conditions of heat transfer from the melt, whereas over large distance from the working surface its temperature does not change [6-7] (figure 4). A simplified scheme of heat removal on the condition that the melt temperature is changing in the direction perpendicular to the contact surface, may be represented by heat conduction equation [8]:

$$c_1\rho_1 \cdot \frac{\partial T_1(x_1,t)}{\partial t} = k_1 \cdot \frac{\partial^2 T_1(x_1,t)}{\partial x_1^2},$$

where - $T_1(x_1,t)$, c_1, ρ_1, k_1 - temperature, heat capacity, density and thermal conductivity of the melt respectively; t - time.

The initial condition

$$T_1(x_1,0)=T_m+\Delta T,$$

where T_m - melting temperature of the sampling metal;

ΔT - degree of the previous melt overheating.

Boundary conditions:

when $x1=0$: $-k_1 \cdot \frac{\partial T_1(0,t)}{\partial x_1}=0$

when $x1=l$:

$$-k_1 \cdot \frac{\partial T_1(l,t)}{\partial x_1}=\alpha[T_1(l,t)-T_2(0,t)],$$

where α - coefficient of heat transfer on the boundary of melt-solid mass;

$T_2(x_2,t)$ - the temperature of solid-mass.

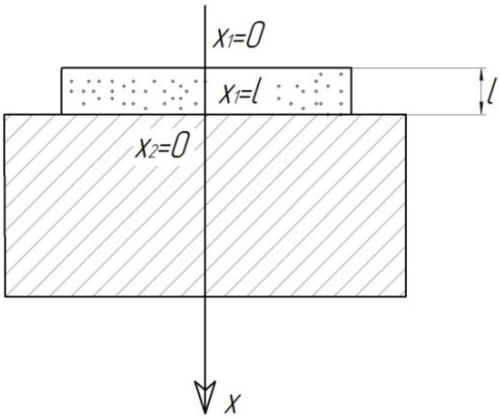


Figure 4 Scheme of cooling:
l – thickness of the melt layer; x_1 – coordinate in the direction of heat transfer within the boundaries of melt layer ($0 \le x_1 \le l$);
x_2 – the coordinate in direction of heat removal within the boundaries of substrate ($0 \le x_2 \le \infty$).

General equation of heat conduction for the relevant material for formalization of the process of heat removal to the solid mass was used, as well as conditions reflecting the physical aspects of the thermal problem:

$$c_2\rho_2 \cdot \frac{\partial T_2(x_2,t)}{\partial t} = k \cdot \frac{\partial^2 T_2(x_2,t)}{\partial x_2^2};$$

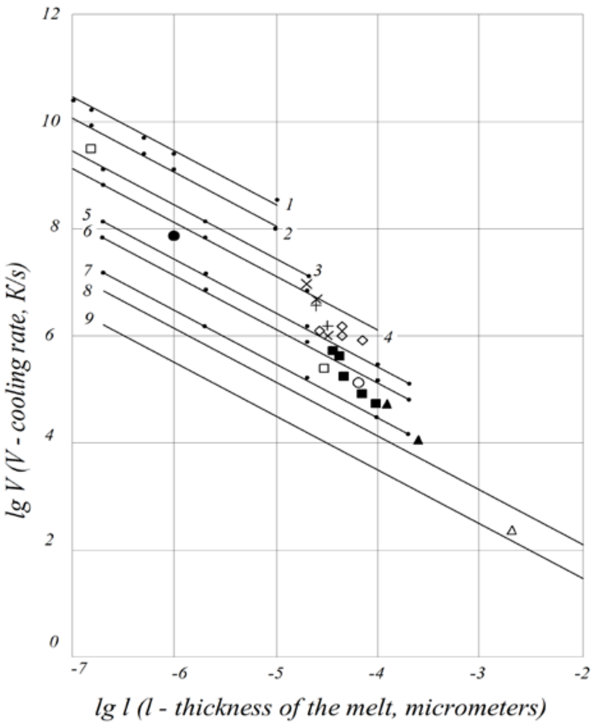
$$T_2(x_2,0)=T_0;$$

$$-k_2 \cdot \frac{\partial T_2(0,t)}{\partial x_2} = -\alpha[T_2(0,t)-T_1(l,t)];$$

where c_2, ρ_2, k_2 - heat capacity, density and thermal conductivity of the substrate;

T_0 - initial temperature of the solid mass (x=0).

In result of solving the equations the dependency diagrams of cooling rate for aluminum and nickel on the thickness of the melt at different values of heat transfer coefficient α are obtained (figure 5).



1) $\alpha=10^7$ W/(м^2 cn); 2) $\alpha=5\cdot10^6$ W/(м^2 cn); 3) $\alpha=10^6$ W/(м^{2}cn);
4) $\alpha=5\cdot10^5$ W/(м^2 cn); 5) $\alpha=10^5$ W/(м^2 cn); 6) $\alpha=5\cdot10^4$ W/(м^{2}cn);
7) $\alpha=10^4$ W/(м^{2}cn); 8) $\alpha=5\cdot10^3$ W/(м^{2}cn); 9) $\alpha=10^3$ W/(м^2 cn);

Figure 5 Dependence of aluminum and nickel cooling rate on the thickness of the melt at different values of the heat transfer coefficient α.

For formalization of the concept of materials structure let us introduce the value - degree of amorphization (metal volume and crystals volume ratio). Figure 6 shows a graph characterizing dependence of the amorphization degree on the thickness of the melted layer and the mass of deposited metal at the cooling rate of 10^4 K/s.

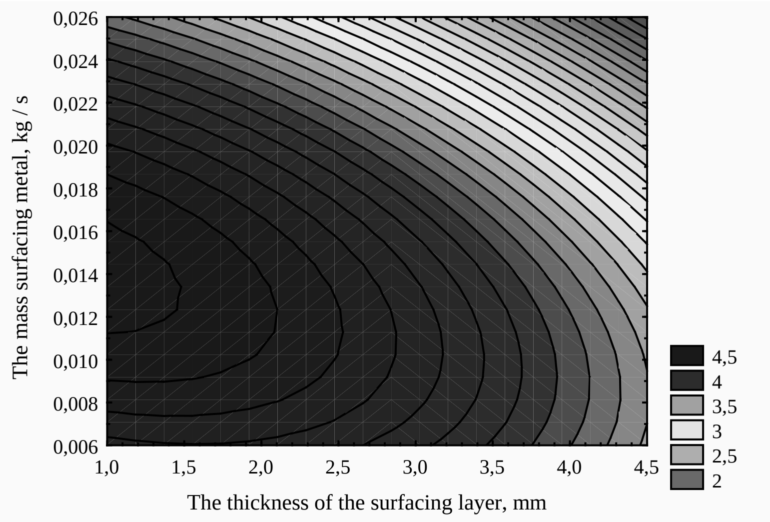


Figure 6 Dependence graph of the degree of amorphization on the thickness of the deposited layer and the mass of deposited metal

Conclusions. As one may see from the graphs the values of cooling rate have significantly advanced with decreasing of the melt thickness. Other technological factors, with the help of which one may control the mode of rapid cooling of the melt, are the degree of overheating of the melt overheating and the initial temperature of the solid mass. With the change of substrate temperature from -200 to 200 ° C, there observed the decrease of cooling rate, so it may be concluded, the lower the temperature of substrate the higher cooling rate. Theoretical calculations even under the simplified mathematical model make it possible to estimate the rate of melt cooling and the probability of obtaining the amorphous structure of the metal.

References

1. Dahlgren, S.D. *Treatise Mater. Sci. and Technol.* (1980), v.19, Exp. Meth., Part A, N.Y., p.213-251.
2. H.Fujimori, N.S.Kazama (1979). 1869-th report on the Research Institute of Iron, Steel and other materials., p.177-192.
3. Metallicheskie stekla (Metallic glasses). Moscow, Metallurgiya, 1984, 264 p.
4. Miroshnichenko I.S. Zakalka iz zhidkogo sostoyaniya (Hardening from the liquid state). Moscow, Metallurgiya, 1982, 168 p.
5. Molodyk N.V., Zenkin A.S. Vosstanovlenie detaley mashin. Spravochnik. (Recovery of machine parts. Reference book). Moscow,Mashinostroenie, 1989, 480 p.
6. Pavlenko, A.M., Basok, B.I., Avramenko, A. A. (2005). Heat Conduction of a Multi-Layer Disperse Particle of Emulsion. *Heat Transfer Research.* 36, (1,2), 55-61.
7. Ruhl R.C. *Mater. Sci. Eng.*, 1967, 1, 313-320 p.
8. Suzuki K., Fujimori H., Hashimoto K. Amorfnyie metally (Amorphous metals). Moscow, Metallurgiya, 1987, 328 p.