Experimental study of modification mechanism at a wear-resistant surfacing

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Abstract. In the study, a simulation of the crystallization process was carried out for the deposition of the near-eutectic structure alloys with inoculants presence in order to reveal the regularities of the inoculant effect and parameters of the process mode simulating surfacing on the structure of the crystallization front and on the nucleation rate and kinetics of growth of equiaxed crystallites of primary phases occurring in the volume of the melt. The simulation technique of primary crystallization of alloys similar to eutectic alloys in the presence of modifiers is offered. The possibility of fully eutectic structure during surfacing of nominal hypereutectic alloys of type white cast irons in wide range of deviations from the nominal composition is revealed.

Keywords: surfacing; wear-resistant alloys; eutectic; modification; simulation technique.

1. Introduction

The high-carbon wear-resistant iron-based surfacing materials having structure of white cast iron are widely applied to surface and volumetric hardening by an arc surfacing of the parts working in the conditions of an abrasive wear in combination with load impact of moderate intensity[1]. But compared to cast products of white wear-resistant cast iron, in the surfaced and sprayed coating, formation of structure and properties take place in strongly non-equilibrium conditions [2, 3]. Therefore coatings have the highest working properties when forming structure different from cast iron product [4, 5].

In surfaced coatings the complex of high working properties (impact value and wear resistance) is reached under following characteristics of structure: [6]:
- the degree of eutectical close to one;
- finely dispersed structure of an eutectic;
- lack of carbides of cementite type etc.;

Existence of dendrites of solid solution in coatings with eutectic structure, considerably reduces the resistibility to abrasing effect. In most cases, presence of fragile primary carbides in the hypereutectic alloys doesn't allow their use even with the minimum load impacts [8].

Features of formation of structure during surfacing (a deviation of a chemical composition of the built-up metal from nominal, rapid mixing, etc.) cause need of receiving a non-equilibrium quaseutectic microstructure of circumeutectic alloys by growth slowdown of primary phases. It is possible under the displaceable crystallization curves [7] and/or under inoculation. The microalloying by elements forming refractory particles in liquid-alloy (in relation to white cast iron – carbides Ti, Y, Nb), has a beneficial effect on creation of the additional centers of crystallization (sort modifiers I) with the following microstructural refinement [9, 10].
The modification by metals with coordinate fusing temperature with the base metal aid changes of the melt properties (viscosity, a surface tension, diffusivity, etc.). Being adsorbed on surfaces of the growing crystallites, they lead to changing of nature of crystallization of separate phases of a eutectic (sort modifiers II).

2. Materials and methods

Modeling of regularities of crystallization under surfacing of the circumeutectic alloys in the presence of modifiers was carried out by a technique of microscopical analysis of processes of hardening of optically transparent materials according to the scheme "motionless bath – the rotating sample" [12] (fig. 1).

As components of model salt system, we have chosen saltpeter $\text{KNO}_3$, ($\text{Melting point} = 334 ^\circ\text{C}$), modeling solid solution, and the $\text{KCl}$ chloride of potassium ($\text{Melting point} = 778 ^\circ\text{C}$) imitating a refractory phase like carbides and restrictedly dissolved in $\text{KN03}$. The eutectic point corresponds to 4,6% of $\text{KCl}$ on the weight and temperature of 312 °C. Chloride sodium $\text{NaCl}$ was used as the sort modifier I ($\text{Melting point} = 801 ^\circ\text{C}$), insoluble in $\text{KN03}$, and $\text{KOH}$ potassium hydroxide as the sort modifier II, which restrictedly dissolved in $\text{KN03}$ and $\text{KSI}$.

![Figure 1. Appearance of a surfacing bath](image)

For modification of a surfacing bath, alloy of salts melted by immersion of a heated spiral of a motionless glow element (see the figure 1). The quantity and the nature of heat sharing entered into a bath are regulated by the heating temperature, form and the sizes of a spiral of an element, and also by rotation speed of the faceplate.

The area of interest of a bath was combined with an optical axis of a microscope and kept its position within sight that provided a continuity of observation process.

During optimisation of methods, crystallization processes researches for the salt system $\text{KNO3} + \text{KCl}$ were made. Mass concentration of $\text{KCl}$ varied from 0 to 6%. Special attention was paid on detection of regularities of influence of parameters of the process mode imitating a surfacing on a structure of the crystallization front (CF) and on intensity of origin and kinetics of equiaxed crystallites growth (EC) arising in fusion volume.

3. Experimental results

The carried out research made it possible to reveal the regularities of the inoculants effect and process parameters imitating surfacing on the structure of the crystallization front and on the nucleation rate and the growth kinetics of equiaxed crystallites of primary phases occurring in the melt volume. Results of observations of crystallization process were fixed with video recording by the digital camera. The CF structure obtained by results of data processing, are given in the figure 2.

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The CF is basically plane for pure saltpeter in the speed range studied (fig. 2 a).EC emergence isn't recorded. Occasionally there are perturbations of plane CF with transition to meshy type of crystallization[13]. There is a step movement of meshy CF, after that the plane CF is recovered. With speed growth of a surfacing the frequency of bounces of CF and their expansion increases[14].
Existence of particles of uncontrollable impurity, accidental mechanical impacts on a fusion and changes of surfacing speed, etc. can be the possible cause of perturbations of FC.

On addition of over 1% of chloride potassium into saltpeter, CF gets strongly marked meshy-dendritic structure when axes of growth of crystallites of the second order are designated. Before CF emergence EC is observed (the figure 2). After origin EC grow mainly in the direction of the basic EC where it is necessary to expect the increased concentration of impurity in fusion. Around growing EC the movement of the basic CF is slowed down. After the contact of dendrites of the basic CF with EC their joint growth begins, and the CF growing from EC has meshy type with thinner structure.

**Figure 2.** Structure of the crystallization front depending on components of modifiers and surfacing speed:

- (a) – $V_{surfacing} = 0.12 \text{ mm/s}$; 
- (b) – $V_{surfacing} = 0.28 \text{ mm/s}$; 
- (c) – $V_{surfacing} = 0.12 \text{ mm/s}$; 
- (i) – $V_{surfacing} = 0.28 \text{ mm/s}$;

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Results of microscopic observations were fixed by video recording. Results of an experiment are presented on the figure 3.

The quasiflat FC typical to crystallization of an eutectic structure alloy under small speed of surfacing of vH is given in fig. 3, and. EC are absent. With increase of vH by 2 – 3 times the
morphology of an eutectic (fig. 3, b) changes. Formation of the eutectic branched dendrites is observed. EC are also absent that confirms the eutectic nature of crystallization.

Violation of quasiflat FC and emergence of small EC of primary phase is observed on addition of small number of 0.25% sort modifier I to the eutectic alloy (fig. 3, c). The effect amplifies under any deviations from the eutectic concentration and with increase of vH. Under surplus of NaCl quantity the EC and speed of their growth promptly increase (overmodification). At the same time the main CF doesn’t change practically.

An effect of the sort modifier II is more complex. The additive of 0.5% KOH to the eutectic alloy gives the effect similar to increase of vH i.e. the eutectic morphology changes (fig. 3, d). The eutectic dendrites become more thinly branched. Under surplus of KOH they are integrated, also there is a high probability of formation large EC of primary phase (fig. 3, j).

In hypoeutectic alloy EC origin becomes active in fusion with their subsequent rapid growth. The CA is almost completely formed from large EC (fig. 3, i). In this case KOH acts as the sort modifier I.

The most interesting is the effect of appending of optimum KOH quantity to hypoeutectic alloys. As a result of growth slowdown of a refractory phase, it is observed completely eutectic crystallization for nominally hypoeutectic alloys with concentration till 7% of KC1 (fig. 2, f). In practice it means a possibility of receiving the eutectic structure under surfacing in the wide range of deviations from nominal structure of alloys [14, 16]. As sort modifiers II for white cast iron, sulfur phosphorus, copper, and other elements can be used. Their search is a separate object of research [12, 13].

4. Results and discussion

The work carried out allows to discover regularities of influence of agents of modifiers and parameters of the mode of the process imitating a surfacing on a structure of crystallization front (CT) and on intensity of origin and kinetics of growth of equiaxed crystallites (EC) of primary phases arising in volume of fusion. Results of microscopic supervision were fixed with video recording.

The quasiflat FC typical to crystallization of an eutectic structure alloy under small speed of surfacing of vH is given in fig. 2a, and. EC are absent. With increase of vH by 2 – 3 times the morphology of an eutectic (fig. 3, b) changes. Formation of the eutectic branched dendrites is observed. EC are also absent that confirms the eutectic nature of crystallization.

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For simulation verification test, an experiment on surfacing flux cored wire of brand PP-AN125 (PP-200H15S1GRT) was performed. Surfacing mode parameters are: arc current – 350 A; arc volts 30... 32 V; surfacing rate - 0.5 cm / page. Structure of the built-up metal is hypoeutectic with primary crystals of austenite.
For obtainment the eutectic and hypoeutectic microstructures, the built-up metal was in addition boron doped by pre-application of a layer of FB20 ferroboron powder to the built-up sample, during surfacing this powder were fixed by zapon lacquer to prevent deflation.

As a sort modifier II silicocalcium was added to ferroboron powder, this choice is based on data of work [18] on efficiency of an silicocalcium additives to the charge flux-cored wire in case of surfacing of high-strength gray cast iron. The quantity of a ferroboron and a silicocalcium per unit area of a sample was being changed.

During the analysis of a microstructure special attention was paid on existence and the size of primary phases and morphology of eutectic. Results of the metallographic analysis are given in the structure chart (fig. 2) and in microstructures (fig. 3).

The chart shows that completely eutectic structure in the absence of the modifier can be obtained in narrow range (2.5...3.0%) of boron concentration austenite dendrites (see fig. 3,а) emerged with reduction of boron concentration, primary carboborite (see fig. 3, j) emerged in case of increase of concentration.

5. Conclusions

With appending 0.2% Ca, the area of the eutectic concentration extends to 2.3... 3.7%. The carbide phase is ground (see fig. 4, f). In case of increase of Ca containing over 0,3% the effect of modifying weakens. The area of the eutectic concentration is narrowed again, the sizes of primary phases considerably increase, i.e. we gain effect of overmodification.

In the available samples We determined deformation of crack origin as a crash-worthiness index and also HRC hardness by a technique [5].In nominally hypereutectic built-up metal after addition of the modifier it was succeeded to reach an increase of crash-worthiness by 2 – 3 times as a result of formation of the quasieutectic microstructure. Hardness of the built-up metal practically didn't change.

It is recommended to add silicocalcium to the charge flux-cored wire of PP-AN125 or PP-AN170 types, and also the surfacing electrodes like T-620 for modifying for the purpose of increase of crash-worthiness of the built-up metal.

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References

[1] Charchenko M V 2010 Energy consumption decreasing in wide strip hot rolling on the base of modeling and effective mode of lubrication rolls choice: diss. of master of techn. sc. Magnitogorsk

[2] Platov S I, Amirov R N, Dema R R and Yaroslavtsev AV 2012 Wearing and working rolls durability predicting mathematical model in cuatro stand at a lubrication supply Proizvodstvo Prokata (Rolled Products Manufacturing) 9 pp 38–43

[3] Dubovskiy S V, Dema R R, Harchenkoand M V and Yaroslavtsev A V 2011 Efficiency of feed technological lubricants in the stand number 7-9 continious broad and strip hot rolling 2000 JSC "MMK" integrated assessment research Proizvodstvo Prokata (Rolled Products Manufacturing) 12 pp 6–8

[4] Ehliot R 1987 Upravlenie ehvtetkischeskim zatverdevaniem [Eutectic solidification management] (Moscow: Metallurgiya) p 352

[5] Nefedyev S P, Dema R R, Nefedyeva S A and Yaroslavtcev A V 2015 Microstructure of cast iron after plasma bleaching Journal of Chemical Technology and Metallurgy 50 2 pp 213–216

[6] Youn T K, Amanov A, Cho I S and Park I G 2011 Effects of ultrasonic nanocrystalline surface modification on the high-frequency fretting wear of CP titanium and Ti-6Al-4V alloy Nanotechnology Materials and Devices Conference (NMDC) (IEEE, South Korea)

[7] Vorozhishechev A N, Dema R R and Kazakova T V 2016 Modeling of a Thermal Massive Body Depending on the Cooling Liquid Volume, as Exemplified by Rolls for a Hot-rolling Mill Procedia Engineering 150 pp 1007–1012

[8] Bojan Podgrornik and Vojtech Leskovcev 2014 Wear mechanisms and surface engineering of forming tools Materials and technology (Ljubljana: Institute of Metals and Technology) 4 pp 313–324

[9] Vineet Shibe and Vikas Chawla 2014 A Review of Surface Modification Techniques in Enhancing the Erosion Resistance of Engineering Components International journal of research in mechanical engineering and technology 4 2 pp 92-95

[10] Emeljushin A N, Petrochenko E V and Nefedyev S P 2012 Comparison of structure and properties of the cast and built-up wear-resistant materials Litejnye processy [Foundry processes] 11 pp 141–145.

[11] Artemenko Yu A, Bartenev D V, Makushenko AV etc. 2008 Research of processes of crystallization under surfacing of wear-resistant alloys on the transparent salt models Tekhnologiya metallov[Technology of metals] 8 pp 41–42

[12] Lasitsa A and Churankin V 2014 Dynamics of wear surface layers modified by complex treatment Dynamics of Systems, Mechanisms and Machines (Dynamics) Omsk, Russia

[13] Youn T K, Amanov A, Cho I S, Lee C S and Park I G 2011 Wear Resistance Characterization for Plated Connectors Nanotechnology Materials and Devices Conference (NMDC) 1

[14] Dema R R, Platov S I Amirov R N and Yaroslavtsev A V 2012 Wearing of working rolls continuous mill 2000 mathematical model at a lubrication supply Latest problem of modern science, technique and education 2 № 70 pp 165–167

[15] Platov S I, Dema R R, Amirov R N and Gatatulina U H 2013 Estimation of wearing material volume changing at at a lubrication supply Mechanical equipment of metallurgical plant 2 pp 16–18

[16] Nefedyev S P, Dema R R and Kotenko D A 2015 Abrasive and impact-abrasive wearing quality of solid surfaced coat Bulletin of the south Ural State University 15 № 1 pp 103–106

[17] Lyubich A I and Pustovgar A V 2002 Silicocalcium influence on structure and properties of the built-up metal Svarochnoe proizvodstvo. [Welding production] 6 pp 46–47

[18] Vorotnikov V Ya, Ivanov S V and Yu A Artemenko 1983 Resistance test technique of the surfacing alloys to shock loads Avtomaticheskaya svarka [Autowelding] 9 pp 61–62