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On the effectiveness of multi-component laser modifying of Fe-based self-fluxing coating with hard particulates

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ABSTRACT

In the present paper, the influence of laser remelting parameters and laser modifying with B_4C, MoB and TaB particulates on the structure, phases, microhardness and wear rates of Fe-based self-fluxing alloy coatings is studied. The laser spot speed, diameter and beam overlap factor influence the changes of alloy structures and composition. The presence of alloyed α-Fe and γ-Fe and a lot of hard inclusions, such as FeB, MoB, TaB and CrB, Fe_3C, VC, Cr_3C_2 and B_4C, was revealed. Laser alloying with add-in reinforced B_4C, MoB and TaB particulates affects the structure and phases composition of the coating significantly. These changes affect the microhardness and wear rate of the coatings.

1. Introduction

The surface condition of machine parts affects many of their properties. An optimum combination of properties of the part material usually represents a compromise between the required surface operational characteristics (wear resistance, corrosion resistance, etc.) and the necessary material properties (strength, toughness, etc.). Parts with optimal properties can be produced by improving their surface processing technology, including coating.

From among the various coating technologies plasma spraying methods have been extensively developed [1,2] and laser methods have been extensively used to form surface layers with good operational properties. They allow the strengthening of the surface by hardening or additional alloying [3–6].

Three groups of materials have a substantial share in the materials used for a laser treatment: Fe-based, Ni-based, and Co-based self-fluxing alloys [7–11]. Self-fluxing alloys are widespread versatile materials in the process of creating wear- and corrosion-resistant coatings. Such alloys have boron and silicone constituents which form low-melting fluxes during the contact of the coating material with the surfaces to be coated. Boron and silicone decrease melting temperature of the coating and increase melt liquidity; solid-state chromium boride and complex carboborides provide hardness and wear resistance of the alloys.

The Ni- and Co-based alloys have very good overall properties but their main disadvantage is the high cost. If the properties of Fe-based alloys were enhanced, the Ni-based self fluxing alloys would be replaced by Fe-based alloys which have a high wear resistance and are relatively cheap [7,12–13].

Iron, carbon, manganese, silicon, boron, and other alloying elements are used as the main elements of the powder mixture to create good operational properties of eutectic Fe-based coatings. These elements form the eutectic and other high-strength components (carbides, borides, complex alloyed phases) which interact among themselves at the temperature of eutectic formation. Such components also provide a high hardness and wear resistance as well as a relatively high ductility of the coating. Because of such alloying, a highly dispersed quasi-eutectic structure is formed in the crystallization. Such specificity largely predetermines Fe-based coatings advantages over other materials [12].

The information about the properties of Fe-based self-fluxing alloys is limited. It was found that the FeCrBSi/FeS composite layer exhibited friction-reducing effects and an obvious wear resistance in different lubrication conditions in comparison with 1045 steel [12]. Fe-based self-fluxing alloys have a good corrosion resistance and make it possible to

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Table 1
The chemical composition of P-Cr4Mn2B4Si2V1 powder.

Elements (wt%)								
Fe	B	Cr	Si	Mn	C	V	Al	Cu
Base	3.3–4.3	3.5–4.5	2.0–2.5	2.0–2.5	1.0–1.2	0.5–0.9	0.05–0.5	0.05–0.5

Table 2
The matrix of 2^3 factorial design.

Nr	X1	X2	X3
1	−1	−1	−1
2	1	−1	−1
3	−1	1	−1
4	1	1	−1
5	−1	−1	1
6	1	−1	1
7	−1	1	1
8	1	1	1

obtain a multiphase structure combining a finely dispersed eutectic with a low hardness and an iron borocarbide hard phase, which is the optimum for rubbing pairs operating at high loads and sliding speeds [12]. The development of particle-reinforced nanostructured iron-based composite alloys for thermal spraying has been described in [14]. Phases and structures of Fe-Cr-Mn-Si-Mo-C coating deposited on AISI 1018 steel substrate using laser cladding have been investigated in [15]. It was found that the featureless phase with a high hardness of 1155 HV was characterized as a metastable solid solution. However, the featureless structure appeared to be very brittle with numerous cracks. The microstructure and wear properties of TiC/FeCrBSi surface composite coating prepared by laser cladding were tested in [16]. It was found that FeCrBSi coatings reinforced by TiC particles revealed a higher wear resistance and lower friction coefficient than that of the substrate and FeCrBSi laser-clad coating. The presence of alloyed α-Fe and γ-Fe and a lot of hard inclusions, such as FeB and CrB, Fe_3C, VC, Cr_3C_2 and B_4C, was revealed in [14].

Laser alloying can be used both for coating new parts and for regeneration of worn parts. Different materials may be used for this purpose: boron carbides [15,16] and pure boron [17], tungsten carbides [18], Fe—Al powder [19], zirconium oxides [20], TiB_2–TiC–Al_2O_3 type of composites [21] and others. Multi-component structures that are formed of additives affect the microhardness, stresses, wear and corrosion resistance. Laser alloying with add-in reinforced B_4C particulates affects the structure and phases composition of the coating significantly. These changes affect the microhardness of the coating [22]. Improving the toughness of thermally sprayed Cr_3C_2-NiCr hard metal coatings by laser post-treatment was studied in [23].

The high cost and technological complexity of plasma spraying methods make them difficult to use for a single-part or small-quantity production. In this case, alloying materials can be deposited to parts in the form of a coating based on binders. Researchers use different binders, that are based on paraffin, varnish, silicate glue, BF-6 glue, water glass, sodium polyacrylate/sodium silicate, liquid ethanol, and so on [24–29].

The aim of the present paper is to study the efficiency of a single-component and comprehensive laser modifying of a Fe-based self-fluxing coating with reinforcing hard particulates introduced to the coating using nitrocellulose glue binder; the microhardness and wear rate of coatings depending on the laser processing conditions and loading level were evaluated in studies.

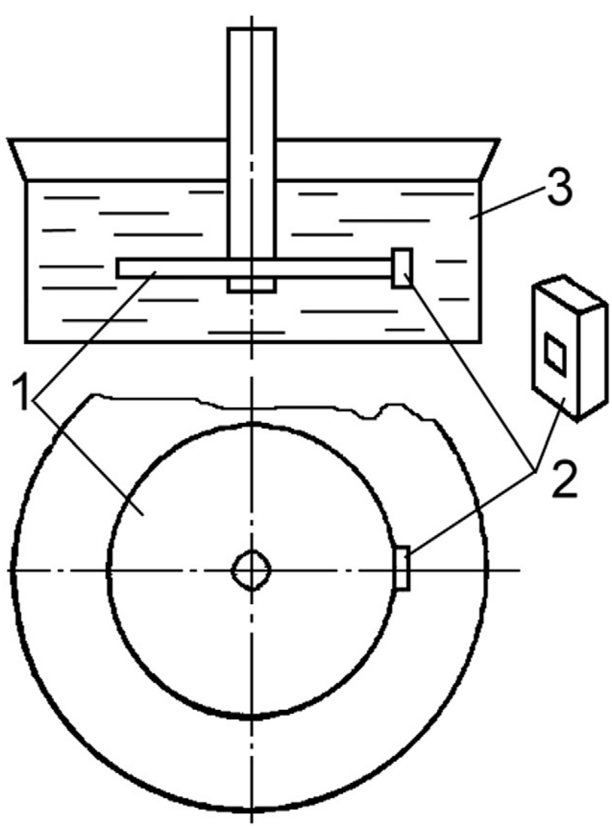

Fig. 1. The schematic diagram of the relative wear studies.

2. Experimental procedure

2.1. Materials

The P-Cr4Mn2B4Si2V1 powder of the Fe-Cr-B-Si system was used for coating (Table 1). The AISI 1045 steel was used as the substrate material and AISI 1045 steel with 40–45 HRC hardness was used as the counter-body material.

For additional laser alloying the following compounds were used: i) tantalum boride (TaB), characterized by a high heat resistance, oxidation resistance, resistance to the action of acids; ii) molybdenum boride (MoB) that has a high resistance to the action of molten metals, high thermal stability, infusibility and thermal conductivity; iii) boron carbide (B_4C) characterized by high hardness, a high abrasion and wear resistance, high heat resistance. The effectiveness of the presence of individual compounds and their mixtures in certain proportions was investigated.

Initial surfaces of samples were subjected to grit blasting, and then a paste which contained a self-fluxing alloy powder and an adhesive was deposited on them. The right choice of the binder is important in the preparation of pastes for adhesive coating, since the laser treatment may cause sooting and decomposition during combustion of most commonly used adhesives, which may lead to periodic shielding of laser emission. As a result, areas are formed that have a large and non-uniform depth of penetration of the substrate, increased porosity and a low content of alloying elements in the coating layer. Binders based on nitrocellulose with a small content of solids combust under the influence of a laser beam forming gaseous products and do not prevent the formation of the coating rollers. Therefore, nitrocellulose adhesive AGO was used as the binder. The paste was prepared by mixing three components: 3% glue AGO, acetone and P-Cr4Mn2B4Si2V1 powder to the consistency of thick cream. Thereafter, a 0.7–0.6 mm thick layer was deposited on the surface of the sample, and the sample was kept