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CONTENTS

TECHNOLOGICAL FEATURES OF WEAR-RESISTANT SURFACING OF METALLIC COMPONENTS ALLOYED WITH CARBON, MANGANESE, AND SILICON USING FUSED FLUXES

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Abstract: The article investigates the wear-resistant surfacing of steel components under flux with alloying of the deposited metal in the C–Mn–Si system without the use of ferroalloys. The effect of the chemical composition of fused fluxes on the microstructure formation, hardness, and wear resistance of the deposited layer is demonstrated.

Key words: submerged arc surfacing; wear resistance; component restoration; fused fluxes; C–Mn–Si alloying.

Annotatsiya: Maqolada po‘lat detallarni flyus ostida qoplash jarayonida qoplangan metallni ferroqotishmalardan foydalanmasdan C–Mn–Si tizimida legirlash masalalari tadqiq etilgan. Eritilgan flyuslar tarkibining qoplama qatlamining tuzilmasi, qattiqligi va yeyilishga chidamliligiga ta’siri aniqlangan.

Kalit so‘zlar: flyus ostida qoplash; yeyilishga chidamlilik; detallarni tiklash; eritilgan flyuslar; C–Mn–Si tizimida legirlash.

Аннотация: В статье исследуется износостойкая наплавка стальных деталей под флюсом с легированием наплавленного металла в системе C–Mn–Si без применения ферросплавов. Показано влияние химического состава плавленых флюсов на формирование структуры, твёрдость и износостойкость наплавленного слоя.

Ключевые слова: наплавка под флюсом; износостойкость; восстановление деталей; плавленые флюсы; легирование в системе C–Mn–Si.

INTRODUCTION

The restoration of worn metallic components represents one of the key challenges in modern mechanical engineering and repair manufacturing, aimed at extending service life and improving machine reliability while reducing material and energy consumption. In this regard, mechanized submerged arc surfacing is of particular importance, as it ensures high process stability and enables controlled formation of the microstructure and service properties of the deposited metal.

To achieve the required wear resistance of restored components, alloying of the deposited layer is traditionally performed using alloying fluxes based on standard fused fluxes such as OSTs-45 and AN-348A with the addition of ferroalloys. However, a significant portion of alloying elements is oxidized and transferred to the slag, which reduces alloying efficiency and overall process cost-effectiveness. In the restoration of mass-produced components, alloying is generally aimed at obtaining hardened microstructures during natural cooling after surfacing, which requires enhanced stability of supercooled austenite and a reduced critical cooling rate.

A promising approach to improving the efficiency of surfacing processes is the application of the C–Mn–Si alloying system without the use of ferroalloys by intensifying metallurgical reactions in the weld pool and controlling the transfer of alloying elements from the flux to the deposited metal. The use of standard fused fluxes with the addition of active deoxidizers ensures effective enrichment of the deposited metal with manganese, silicon, and carbon, improves its microstructure, and significantly enhances wear resistance.

The objective of this study is to investigate the influence of the composition of fused fluxes providing alloying of the deposited metal in the C–Mn–Si system on the microstructure, hardness, and wear resistance of deposited layers during the restoration of steel components.

LITERATURE REVIEW

To ensure the required service performance of restored components, the deposited metal is commonly alloyed with various elements. For this purpose, alloying fluxes—mixtures based on standard acidic fused fluxes such as OSTs-45 and AN-348A with additions of ferroalloys—are frequently employed. However, the efficiency of this approach is limited, as part of the ferroalloy additions undergo oxidation and are transferred to the slag. In the restoration of large batches of components, alloying of the deposited layer is generally intended to produce hardened microstructures during spontaneous cooling of the component after surfacing. Consequently, the primary objective of alloying in this case is to increase the stability of supercooled austenite in order to reduce the critical cooling rate required for hardening.

In recent years, publications by Golovko V.V., Grigorenko G.M., Kostin V.A., and Ryabtsev I.A. have emphasized the significant role of deoxidizing elements as effective control factors for improving microstructure and enhancing the wear resistance of cast metal. Most of these studies have been conducted in the context of welding and surfacing of low-alloy steels. In this framework, the formation of inclusions such as oxides, carbides, and nitrides in the weld metal has been considered a result of chemical reactions occurring during solidification, while inclusions with sizes up to 1 μm have been shown to act as inoculants [1–5]. In other studies, the formation of non-metallic inclusions was associated with the direct introduction of oxides and carbides into the weld pool [6,7]. In all cases, inclusions with appropriate composition, size, and distribution density were found to have a beneficial effect on the microstructure and properties of deposited layers. At the same time, available data on their influence on the wear resistance of deposited metal remain limited. Nevertheless, existing experience with the use of oxides in plasma surfacing [8] and carbides in electrode coatings [9] indicates the strong potential of this approach in surfacing technologies.

The restoration of the serviceability of such components can be effectively achieved by submerged arc surfacing using the C–Mn–Si alloying system without the application of ferroalloys. Sufficient enrichment of the weld metal with manganese and silicon can be attained through the intensification of metallurgical processes during surfacing under standard fused fluxes such as OSTs-45 and AN-348A with the addition of active deoxidizers [1].

RESEARCH METHODOLOGY

To obtain deposited metal with different contents of the target alloying elements, the following flux mixtures were used.

1. AN-348A flux with aluminum additions in the form of PAK-1 powder (GOST 5494-50) in amounts ranging from 2–6 wt.%. Sodium silicate liquid glass with a density of 1.45 was used as a binder in an amount of 15 wt.% relative to the dry mixture. This flux composition promotes an increased transfer of manganese and silicon into the weld metal.
2. OSTs-45 flux with calcium carbide additions (GOST 1460-63) in amounts of 5–20 wt.%. The calcium carbide was preliminarily crushed into granules with a particle size of 0.1–0.3 mm. Under these conditions, effective enrichment of the weld metal with carbon, manganese, and silicon occurs.

Surfacing was performed on flat and cylindrical specimens and components manufactured from steel 45 using Sv-08 wire (GOST 10548-63) with a diameter of 2 mm. The surfacing parameters were as follows: arc voltage 20–30 V, welding current 160–180 A, wire feed rate 120 m/h, and surfacing speed 24–27 m/h.

The influence of flux composition on the microstructure and hardness of the deposited metal obtained by single-layer surfacing is presented in Table 1, while the chemical composition of the deposited layers is given in Table 2. Investigation of the primary microstructure was carried out according to the methodology of the

E. O. Paton Electric Welding Institute [2]. The results demonstrated that all deposited layers were characterized by dendrite refinement and the formation of a cellular microstructure. At the same time, an increase in resistance of the deposited layer to crack formation was observed with increasing carbon content. These effects can be attributed to the modifying action of aluminum and calcium (Table 1).

Table 1. Effect of Flux Composition on Microstructure and Hardness of the Deposited Layer

Sample No.	Flux	Microstructure	Hardness (HRC)
1	AN-348A + 2% PAK-1	Troostite	38
2	AN-348A + 4% PAK-1	Troostite–martensite	46
3	AN-348A + 6% PAK-1	Martensite	55
4	OSTs-45 + 5% CaC_2	–	56
5	OSTs-45 + 10% CaC_2	Martensite + austenite	25–35
6	OSTs-45 + 20% CaC_2	Austenite + carbides	< 20

The data presented in Table 1 demonstrate a clear relationship between flux composition, microstructural evolution, and hardness of the deposited layers. Increasing the content of active additives promotes the formation of harder structural constituents, such as martensite and martensite–austenite mixtures. Flux systems containing calcium carbide result in a wider hardness range, reflecting the influence of carbon enrichment and phase heterogeneity on the mechanical properties of the surfaced metal.

ANALYSIS AND RESULTS

An increase in the manganese content of the weld metal to approximately 3% promotes the formation of hardened microstructures during natural cooling. A further increase in manganese content leads to the formation of metastable manganese austenite, which is capable of strain hardening under high contact stresses due to its transformation into martensite.

Laboratory tests of the relative wear resistance of the deposited layers under sliding friction with an abrasive interlayer were carried out using the gravimetric method based on the Brinell scheme. Quartz sand with a particle size of 0.3–0.5 mm was used as the abrasive medium. Steel 45 with a hardness of HRC 40 served as the reference material. The test conditions were as follows: specific load of 4 kgf per 1 mm of disk width, sliding distance of 305 m, sliding speed of 0.5 m/s, and fivefold repetition of each experiment.

Analysis of the experimental results presented in Table 3 demonstrates that all considered restoration variants provide wear resistance equal to or exceeding that of heat-treated steel 45 (Table 2).

Table 2. Chemical Composition of the Deposited Metal by Sample (%)

Sample No.	Element Content in the Deposited Metal (%)				
	C	Mn	Si	Al	Ca
1	0.46	2.07	0.65	0.02	-
2	0.48	2.75	0.89	0.03	-
3	0.48	3.11	1.30	0.05	-
4	0.82	3.24	0.64	-	0.05
5	1.03	4.30	0.72	-	0.10
6	1.78	6.46	1.04	-	0.15

To validate the obtained results under real operating conditions, field tests were conducted on track rollers of a 3-ton traction-class tractor restored using different surfacing variants. Wear measurements were performed using a micrometer at five circumferential zones of each roller. Each test was repeated four times to ensure reproducibility.

The installation scheme of the rollers on the tractor involved their paired placement on the front and rear bogies, which made it possible to assess the effect of non-uniform specific loading on roller wear (Table 3).

Table 3. Relative Wear Resistance of the Deposited Metal under Laboratory and Field Conditions

Restoration Variant	Relative Wear Resistance of the Deposited Metal	
	Laboratory Tests	Field Tests
1	1	-
2	1.13	1.18
3	1.15	1.28
4	1.16	1.26
5	2.96	1.66
6	1.85	1.60
Reference	1	1

The results of the study (see Table 3) confirmed the findings of the laboratory tests. All considered restoration variants demonstrated sufficient wear resistance under operating conditions. The highest wear resistance in both laboratory and field tests was observed for the deposited layers produced according to Variant 5. This performance can be attributed to the chemical composition of the deposited metal, which provides the most favorable combination of structural constituents. The content of retained austenite in the microstructure of the metal deposited using this variant is approximately 20%.

CONCLUSION AND RECOMMENDATIONS

For the restoration of the serviceability of worn components by submerged arc surfacing, the application of the C–Mn–Si alloying system is considered effective and technically justified in a number of cases.

The use of flux mixtures containing active deoxidizing additives is a viable approach for restoring components whose performance properties can be achieved through alloying with manganese and silicon.

Furthermore, the obtained results demonstrate that controlled alloying of the deposited metal through flux composition provides an effective means of tailoring the microstructure and wear resistance of the surfaced layers. The proposed approach enables the formation of favorable structural states without the use of ferroalloys, thereby improving process efficiency and expanding the technological potential of submerged arc surfacing for the restoration of steel components.

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