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Increasing corrosion resistance of carbon steels by surface laser cladding

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Abstract. This paper presents results of investigation of the microstructure, elemental composition and corrosion resistance of the samples of low-alloy steel widely used in the engineering, after the application of laser cladding. The level of corrosion damage and the corrosion mechanism of cladded steel samples were established. The corrosion rate and installed discharge observed at the total destruction of cladding were obtained. The regularities of structure formation in the application of different powder compositions were obtained. The optimal powder composition that prevents corrosion of samples of low-carbon low-alloy steel was established.

1. Introduction

A large number of machinery parts go out of order a result of abrasion, erosion, corrosion, and so on. Modern technology offers different methods to increase lifetime of details. One such method is laser cladding (LC) [1]. Laser cladding is a perspective and actively developing method of restoring worn parts and create a new application by high corrosion-resistant low-alloy powders on low carbon steel parts. There are manufactured and reducing surfacing [2]. Surfacing is performed by applying a molten metal on the surface of the product has been heated to the melting point or to a temperature reliable wetting liquid weld metal [3]. Cladding layer is integrally formed with the base metal. At the same time the chemical composition of the cladding layer may differ significantly from the composition of the base material. The thickness of the cladding metal (alloy), formed by one or more layers may be different - up to 0.5 mm or more [4].

Besides the above mentioned main goals of LC is improving the corrosion resistance of various parts and assemblies of mechanisms originally made from the cheapest low-carbon low-alloy steels [5]. In this regard, the details of the creation of such steels with LC increase the performance, which in turn is a perspective objective of modern engineering production [6, 7]. The objective of this work is to study the laws of corrosion destruction of samples with different types of LC based on iron and cobalt and choice the optimal composition of the powder and technological conditions applying LC.

2. Materials and Experimental Methods

Experiments on the application of various laser claddings were carried out at two different laser systems: Huffman HC-205 manufactured by HUFFMAN (USA) and "Scanner" (co-production of US-Russia). Huffman HC-205 is a new generation of precision surfacing equipment to the ytterbium fiber laser emission power from 600 to 1000 Watts. Feature Position "Scanner" is the presence on the scanning surface to be treated with the laser head emission capacity from 800 to 1300W. In both installations were used powder dispenser THERMACH Power Feeder AT-1200, which provides precise metering and continuous supply of the powder onto the sample surface at different angles in an argon atmosphere.

Laser cladding was applied to flat substrates made of low-alloy mild steel type St10. Cladding deposited in the form of pure powder brands PR-10R6M5 and 2537 and mixtures. Compositions of powders and their relative proportions in the mixture are shown in tables 1 and 2, respectively.

Table 1. Chemical composition of powders for claddings.

Powder mark	Chemical composition (wt. %)									
	Fe	C	Cr	W	Mo	Si	Mn	Ni	S	Co
PR 10R6M5	80	1	4	6.5	5.2	0.5	0.55	0.4	0.03	-
2537	3	0.9-1.2	27.5-29.5	4-4.8	−	0.9-1.3	−	3	-	57.2-60.7

Table 2. Quantitative ratio of applied powders.

Sample No	Mark of the deposited powder	
	PR-10R6M5 (wt. %)	2537 (wt. %)
0	0	0
1	100	0
2	75	25
3	50	50
4	25	75
5	0	100

Corrosion tests on the intergranular corrosion were carried out of modernized method of AMU (GOST 6032-2003).

In accordance with GOST 6032-2003 test method of AMU conducted by exposing samples of corrosion-resistant steels for 8 hours in boiling aqueous solution containing 50 g / dm^3 $CuSO_4$ and 250 cm^3 / dm^3 H_2SO_4.

Taking into account that the samples of carbon and low-alloy steels for the tests on the intergranular corrosion subjected to considerable degradation, in comparative corrosion study was selected a "soft" mode test: samples were kept for 8 hours in a boiling aqueous solution containing 120 g / dm^3 $CuSO_4$ and 120 cm^3 / dm^3 H_2SO_4.

The calculation of the corrosion rate V_k was performed by their weight loss after exposure to boiling aqueous solution. Samples were weighed with precision ± 0.01 mg of electronic analytical balance GR-202 (A & D, Japan).

Research of topography and surface microstructure, determination of the nature of corrosion interaction and elemental composition of the samples was carried out by scanning microscopy in analytical instrument EVO 50 XVP produced by Carl Zeiss (Germany). The distribution of elements along and across the LC investigated in the wave spectrometer INCA Wave-500, manufactured by Oxford Instruments (UK) with a resolution of 5 eV and a sensitivity of 0.01% (wt.).

Microhardness of samples was measured by the Vickers method on the unit HVS-1000 (China) with automatic loading of the indenter in the largest load for p = 1 N. Time under load was 20 s. The relative error in determining the value of the microhardness of not more than ± 7%.

3. Results and Discussion

It was investigated four types of samples in the work: without cladding (sample No.0) and surfacing of various compositions (samples No.2–No.5). Sample without surfacing is a standard for comparing the corrosion resistance of a pure sample and surfacing samples (samples No.2−No.5).

A study of the microstructure and elemental composition of the samples after corrosion tests by measuring the rate of general corrosion and corrosion buildups, defined the nature of corrosion, depending on the composition of the deposited powder. To select the optimal composition which has the best corrosion resistance, were using the following parameters: the lowest rate of general corrosion and the lowest rate of corrosion cladding, the best coupling of a covering with the substrate (no discontinuities at the substrate-surfacing), minimal heat-affected zone. Analysis of the data (Table 3) showed that the best corrosion resistance has a sample with cladding No.5 (as surfacing material used pure powder brand 2537): the rate of general corrosion of 37.81 g / (m^2 · h), the rate of corrosion surfacing 0.021 g / (m^2·h). This sample has the lowest recorded speed of corrosion, a satisfactory grip surfacing to the surface (no pores, cracks and delamination) and virtually no heat-affected zone (HAZ). Should be noted that all tested samples has satisfactory adhesion to the substrate, and the HAZ is virtually absent, but of the corrosion rate is somewhat higher than the sample №5. The highest rate of general corrosion and corrosion cladding installed in the sample No.2 (as surfacing material was a mixture of powders brand PR-10R6M5 (75 wt.%) and 2537 (25 wt.%)) − 41.97 g / (m^2·h) and 0.42 g / (m^2·h), respectively. The corrosion rate of the reference sample without deposition (sample No.1) is somewhat lower − 41.45 g / (m^2·h).

Table 3. Experimental certain corrosion rate of various samples with LC

Sample No.	The corrosion rate, g/(m^2·h)	Corrosion rate of cladding, g/(m^2·h)
0	41.45	–
1	39.84	0.25
2	41.97	0.42
3	40.55	0.31
4	39.11	0.17
5	37.81	0.021

It is also established that based on the claddings of powder brand PR 10R6M5 the mechanism of intergranular corrosion is typical, which increases with the content of the powder brand in 2537 is replaced by the mechanism of surface pitting. For the sample without cladding (sample No.0) characteristic is the surface (uniform) corrosion.

Figure 1 shows images of the microstructure of samples No.0 (a), No.1 (b) and No.5 (c) to demonstrate the different types of corrosion damage. In areas like cladding and fine-meshed structure of the substrate is observed. It was found that samples No.1–No.4 character of intergranular corrosion damage, while the sample No.5 – superficial ulcerous. For samples with cladding based on the powder brand PR-10R6M5 boundary cells are observed accumulations of corrosion products and cracked. For samples with a weld overlay based on the brand 2537 (starting from 50 wt.%) no segregations and cracks. Figure 2 is an end to the grinding areas of layered element analysis claddings No.1 (a) and No.5 (b).

As shown by the analysis of the composition of elements in corroded cladding different for samples No.1 and No.5. For sample No.1 is characterized by a large number of isolation oxide mainly iron and chromium - elements that are present in the composition of the cladding.

For sample No.5 no selections were found. It is also noted that when the deposited powder mixture the border of cladding-substrate is wavy, while the deposited pure powder of the same brand − line (figure 2).

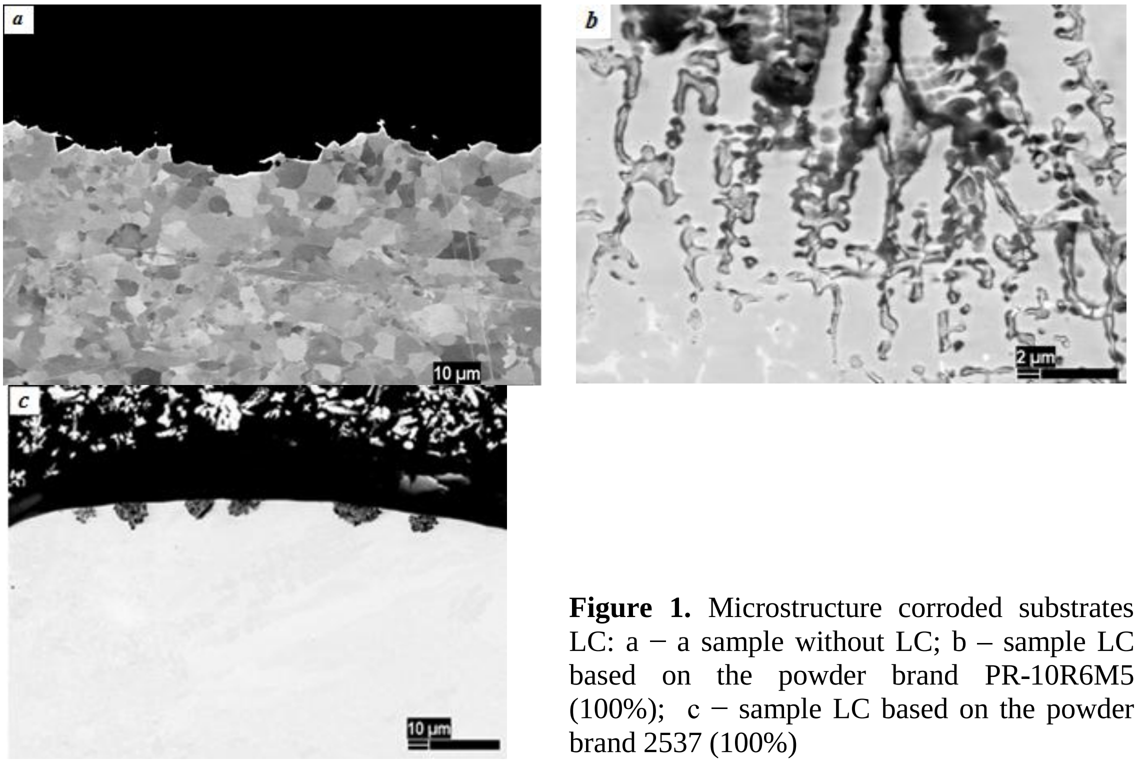

Figure 1. Microstructure corroded substrates LC: a − a sample without LC; b – sample LC based on the powder brand PR-10R6M5 (100%); c − sample LC based on the powder brand 2537 (100%)

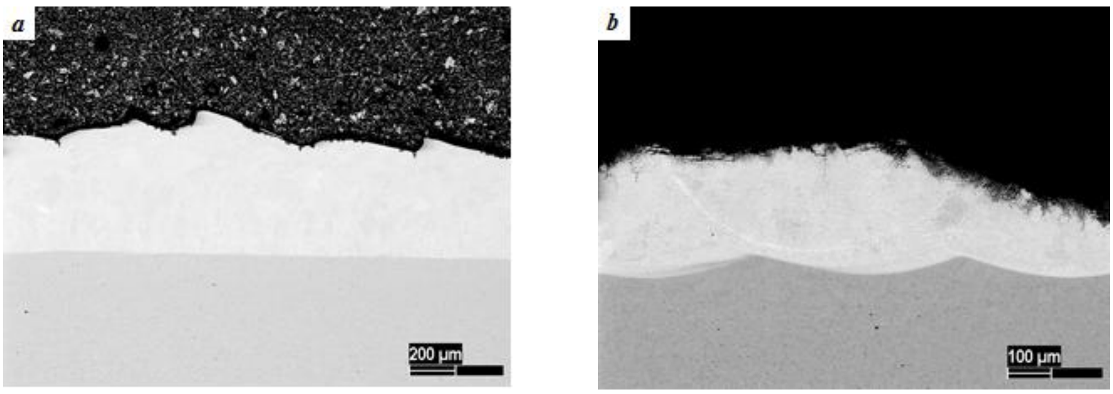

Figure 2. Melting area cladding with the substrate: a – LC substrate based on pure powder of the same brand; b − LC substrate based on a mixture of powders of different grades

Based on researches, the optimal composition of the powder is set for maximum corrosion resistance of samples in a medium boiling aqueous solution containing 120 g / dm^3 $CuSO_4$ and 120 cm^3 / dm^3 H_2SO_4. Revealed that with decreasing amounts of iron and cobalt content increases in the cladding, the corrosion rate decreases. The presence of small amounts of nickel able to slow down the corrosion process, even with high content of iron. The optimum is cladding based on the pure powder brand of 2537 based on the cobalt, can significantly reduce the speed of the corrosion process.

4. Conclusions

It is shown that all the LC have a close-meshed microstructure and rather uniform distribution of the alloying elements on cladding volume.

It is established that at all claddings coupling with a substrate the satisfactory: cracks, peeling and the pores on the boundaries of the substrate-surfacing were not found. All surfacing HAZ is virtually nonexistent.

It is revealed that when fusing one type of powder border of substrate-cladding direct, and when fusing mix of powders (irrespective of a percentage ratio) border of substrate-cladding becomes wavy.

It is revealed that at cladding based on PR-10R6M5 brand powder the mechanism of intergranular corrosion is predominant, and at cladding based on brand 2537 powder is dominated by the mechanism of surface pitting.

The optimum composition of the cladding (pure powder brand of 2537), has the lowest rate of total corrosion and corrosion cladding constituting 37.81 g / ($m^2 \cdot h$) and 0.021 g / ($m^2 \cdot h$), respectively.

Thus, as result of the conducted researches, was established the optimal composition by anti-corrosion properties of LC powders, allowing to increase service life and decrease corrosion of the wares based on low-carbon low-alloy steels by more than 3 orders of magnitude.

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