Improving the Performance Characteristics of the Drawing Machine Intermediate Block Working Surface by Additive Technologies

L V Radionova, M N Samodurova and B A Chaplygin

Department of Processes and Machines for Metal Forming, South Ural State University, 76, Lenin prospekt, Chelyabinsk, 454080, Russia

E-mail: radionovalv@susu.ru

Abstract. This paper presents the study results of the drawing machine intermediate block surface hardening treatment by the methods of additive technologies. Laser surfacing of powder material Fe-4.5Cr-4.5Mo-5.5W-4V on the intermediate block working surface a wear-resistant layer with a hardness of 52-54 HRC with a thickness of more than 1.5 mm. The laser complex LaserClad 4 C R120 based on the industrial robotic manipulator KUKA KR-120 together with the positioner is able to melt powder material only on the working surface of the intermediate block, thereby significantly reducing its cost and labor intensity during its manufacture. The applying of detonation spraying with subsequent penetration for this type of product proved to be ineffective. The detonation coating itself with a powder material based on tungsten carbide turned out to be uniform and had a hardness in the range of 61-65 HRC. But rather large pores and cracks appeared in it after penetration, which is associated with a significant difference in the coefficients of thermal linear expansion of steel 41Cr4 (14·10−6 1/K) and an alloy based on tungsten carbide (3.9·10−6 1/K).

1. Introduction

Drawing is the main method for producing wire, both commercial and in the form of a blank for the production of hardware, for example: nails, mesh, fasteners and ropes [1–7]. Drawing mills of various types are used as the main equipment for the wire manufacture [8]. All of them are united by the presence of such structural elements as an intermediate block, a “soap box” with a drawing holder, a die, a motor, a gearbox and a stand.

A single and multiple drawing mill was designed and manufactured at the department “Processes and Machines for Metal Forming” for research purposes, as well as for the training of specialists in the hardware production field (Figure 1) [9, 10].

The designers are faced with the question of how and from what material intermediate block should be made when designing a drawing machine. The drawing machine intermediate block is one of the most loaded units. The surface of which is subject to wear during operation, in addition, its design features require machining, which significantly increases its cost. The block surface must be smooth and hard so that the wire can slide along the block to carry out the drawing process, and the lower turn can push the accumulated turns up along the block surface. In this regard, a thick-walled tube made of 41Cr4 steel was chosen as a workpiece for production, it was supposed to use a hardening treatment such as surfacing to create a functional working layer on its surface.
2. Materials and methods

The capabilities of the SUSU Laboratory for Mechanics, Laser Processes and Digital Production Technologies namely the KLS complex based on LaserClad 4 C R120, equipped with an LS-4 ytterbium fiber laser, an industrial robot-manipulator KUKA KR-120 and detonation complex CCDS2000 [11] were used to carry out cladding and obtain a wear-resistant surface layer of the intermediate block.

The purpose of this work is to develop a technology for obtaining a functional surface layer of a drawing machine intermediate block with increased operational properties. The technology for obtaining a functional layer was tested on modeling samples (Figure 3) since the intermediate block (Figure 2) is a rather massive product, its diameter is 400 mm, and its weight is more than 50 kg.

Two methods of surface hardening were considered to obtain a functional surface layer: detonation spraying followed by laser treatment of the applied layer and laser cladding of a powder material.

Castoline powder 55586C (WC-10Co-4Cr) was chosen for detonation spraying, and EuTroLoy® 16606 powder (Fe-4.5Cr-4.5Mo-5.5W-4V) for direct laser fusion. Tungsten carbide powder (WC-10Co-4Cr) is used to protect against wear and corrosion at temperatures below 480 °C. Fe-4.5Cr-4.5Mo-5.5W-4V powder has excellent wear resistance when working up to 500 °C.

The surface of the samples (substrate) made of steel grade 41Cr4 (Figure 3), before the application of the hardening layer, was subjected to cleaning in an abrasive-blasting cab.

Thirty five shots were made with a powder based on tungsten carbide WC-10Co-4Cr during detonation hardening with subsequent fusion penetration onto the substrate. The resulting coating was
uniform. Metallographic sections were made to study the microstructure and determine the microhardness. The samples were etched with a 3% solution of nitric acid in ethyl alcohol.

Figure 3. Samples (substrate) from steel grade 41Cr4.

3. Results and discussion

Metallographic examination showed that the thickness of the coating is within 0.25 mm (Figure 4) and that the coating is very dense and uniform. The adhesion zone of the coating to the base metal is shown in Figure 5. The performance characteristics of the surface layer were evaluated through hardness. Determination of microhardness was carried out using a universal stationary hardness tester HV-1000 (Table 1). The measurement results and the conversion of the obtained values into HRC units are shown in Table 1.

The resulting layer was melted on a laser facility after detonation spraying. It was revealed that cracks and pores are present in the layer in the course of metallographic studies (Figure 6).

Figure 4. Detonation spraying layer (x100).

Figure 5. Area of the base metal and the applied layer adhesion (x500).

Table 1. The results of the surface layer obtained by detonation spraying hardness measuring.

| Measurement number | 1    | 2    | 3    | 4    | 5    |
|--------------------|------|------|------|------|------|
| Hardness, HV       | 840  | 733  | 763  | 763  | 727  |
| Hardness, HRC      | 65.3 | 61.8 | 62.5 | 62.5 | 61.5 |

The cracks formation reason is a significant difference in the coefficients of thermal linear expansion of steel 41Cr4 (14 × 10⁻⁶ 1/K) and an alloy based on tungsten carbide (3.9 × 10⁻⁶ 1/K) in our opinion [12–14]. The fused layer thickness over the entire surface varies from 0.41 mm to 0.67 mm (Figure 6). The microhardness measurements were carried out according to the scheme shown in Figure 7, and the results of these measurements are shown in Table 2.
Figure 6. Remelted layer (x100).

Figure 7. Scheme of microhardness measurement after melting of the layer applied by detonation spraying.

Table 2. The results of detonation sputtering surface layer with followed by fusion hardness measuring the of the.

| Measurement number | 1  | 2  | 3  | 4  | 5  | 6  | 7  | 8  |
|--------------------|----|----|----|----|----|----|----|----|
| Hardness, HV       | 857| 876| 903| 822| 723| 527| 541| 551|
| Hardness, HRC      | 65.9| 66.4| 67 | 64.7| 61.4| 51.1| 51.7| 52.3|

Direct laser fusion of the powder material was used for the third hardening method. The metal powder Fe-4.5Cr-4.5Mo-5.5W-4V was deposited on the substrate using the previously developed mode [15] (Table 3).

Table 3. Powder alloy Fe-4.5Cr-4.5Mo-5.5W-4V welding mode.

| Collimator position | Power (Watt) | RPM% | V (mm/s) | Spot d, mm | Displacement |
|---------------------|--------------|------|----------|-------------|--------------|
| 0                   | 1200         | 12   | 12       | 3           | 1.4          |

The results of the obtained layer metallographic studies showed that there are no cracks and microcracks in the structure, as well as the deposited layer porosity does not exceed 3% (Figure 8). The thickness of the deposited layer is 0.73… 0.76 mm (Figure 8). The thickness of the directional layer can be increased, since there are no technological obstacles for this. The microstructure of the deposited layer is shown in Figure 9.
A base material layer of steel grade 41Cr4 subjected to thermal action during the cladding is formed under the deposited layer [16]. The microstructure of this area is shown in Fig. 10. The thickness of the heat-affected zone is about 0.6 mm. A martensite zone with a thickness of about 0.3 mm is formed under the deposited layer in this case. Therefore, the hardened layer is about 1.5 mm in total. The results of the deposited layer hardness measuring are given in table 4.

| Measurement number | 1  | 2  | 3  | 4  | 5  |
|--------------------|----|----|----|----|----|
| Hardness, HV       | 570| 555| 555| 551| 551|
| Hardness, HRC      | 53.6| 52.4| 52.4| 52.3| 52.3|

4. Conclusions
It was found that it is advisable to use laser surfacing of a powder material of the composition Fe-4.5Cr-4.5Mo-5.5W-4V for increasing the wear resistance of the working surface of the drawing machine intermediate block. It provides a hardened layer with a hardness of 52–54 HRC to at least 1.5 mm depth. The laser complex LaserClad 4 C R120 based on the industrial robotic manipulator KUKA KR-120 together with the positioner is able to melt powder material only on the working surface of
the intermediate block, thereby significantly reducing its cost and labor intensity during its manufacture.

The applying of detonation spraying with subsequent penetration for this type of product proved to be ineffective. The detonation coating itself with a powder material based on tungsten carbide turned out to be uniform and had a hardness in the range of 61–65 HRC. But rather large pores and cracks appeared in it after penetration, which is associated with a significant difference in the coefficients of thermal linear expansion of steel 41Cr4 (14·10−6 1/K) and an alloy based on tungsten carbide (3.9·10−6 1/K).

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