Determination of properties of cermet coatings obtained by additive laser technologies

V P Biryukov
Mechanical Engineering Research Institute of the Russian Academy of Sciences, 4 Maly Kharitonyevskiy Pereulok, Moscow, 101990, Russia
Laser-52@yandex.ru

Abstract. The paper presents the results of metallographic and tribological studies of 40Kh steel and multi component coating (Ni-Cr-B-Si, Co-Cr-W-Ni-B-Si) with the addition of 5 and 10 vol.% nano-tungsten carbide powder to the charge. The regularities of changes in the friction coefficients from pressure, sliding speed, jamming load from sliding speed and wear intensity of steel and surfaced coatings are shown.

1. Introduction
Additive laser processes play an important role in modern machine-building production. Surfacing experiments were performed using a 4 kW IPG fiber laser. The optical head with a coaxial nozzle was moved by a 6-axis robotic system [1]. Low-carbon steel samples with dimensions of 100×45×45 mm were used as a substrate. For laser surfacing, a composite powder material containing spherical particles of H13 steel with a size of 50 – 150 μm, and crushed titanium carbide (TiC) 30, 40, 50, 60, 70 and 80% of the charge composition with a size of 60 – 150 mm was used. The total feed rate of the powder was 9-10 g·min⁻¹. Typical technological parameters used for surfacing were the laser power density of 180-220 W·mm⁻², the spot diameter of 4 mm, and the travel speed of 0.2-0.3 m·min⁻¹. In addition, the protective gas argon was used, at a flow rate of 10 l·min⁻¹. The first layer was deposited with H13 powder. The highest average hardness of the TiC/H13 composite is 1365 HV at 80% TiC, which is more than twice the hardness of H13 - 644 HV substrate. As the TiC content increases, the average hardness increases. Thus, at 30% TiC in the charge, the average hardness of the deposited layers is 787 HV.

For laser surfacing of WC-10Co-4Cr powder with a particle size of 11-45 μm, flat samples of AISI–SAE 1020 steel with dimensions of 76×25×6 mm were used [2]. Processing was performed using a 4kW Yb: YAG Trumpf TruDisk 6002 laser system equipped with a powder feeder, a beam with a diameter of 3.8 mm with a pulse duration of 0.014 s and a frequency of 50 Hz. The energy density of the laser beam was 24.32 and 39 J·mm⁻² at a speed of 10 mm·s⁻¹. The results of metallography showed that at an energy value of 24 J·mm⁻², the porosity was about 11%, while the mixing of the coating with the base was at the level of 15%. Increasing the energy density reduces porosity by up to 4% and increases mixing by up to 25%. The maximum microhardness value of 1200 HV was obtained at an energy density of 24 J·mm⁻². As the energy density increases, the grain size increases and the microhardness drops to 1000 HV.

Samples made of SS 304 steel with dimensions of 50×25×6 mm were surfaced using Inconel 718 and TiC powders with particle sizes of 43-100 μm and 5-20 μm, respectively [3]. The first batch of
pre-coated samples using a 1 mm thick binder was deposited at a radiation power of 1200 W, a travel speed of 200-1200 mm·min⁻¹, and a laser spot diameter of 3 mm. The content of titanium carbide in the charge for surfacing was 30, 50 and 70%. The second batch of samples was processed using a powder feeder, according to the following modes: powder consumption 8-28 g·min⁻¹, laser beam diameter 2.2 mm, radiation power 400-1200 W. It was found that the lifetime of the molten bath in the range of 0.25 < τ ≤ 0.45 s leads to a good quality of the deposited rollers. Longer life time of the melt of 0.45 with the above, leads to complete decomposition of TiC particles.

Stainless steel 304 plate with dimensions of 160 × 80 × 10 mm is used as substrates for laser surfacing of sintered WC-12Co composite powder with a spherical particle size of 125-180 μm [4]. The treatment was performed on a laser system (LMD8060) containing a LaserLine LDF 3.000-60 diode laser. The following modes were used: radiation power 900, 1100, 1300, 1500, 1700 and 1900 W, beam travel speed 500 mm·min⁻¹, laser spot diameter 2 mm, powder consumption 0.5 g·min⁻¹, track overlap coefficient 50%, thickness of the deposited layer for three passes 2 mm. Tribological tests of coatings at room temperature were performed according to the scheme disk (deposited sample) – ball (Al₂O₃ with a diameter of 6 mm), on a Tribometer (TNT-1000), under friction conditions without lubricant. The sliding speed was 0.2 m·s⁻¹ and the friction path was 200 m. Each sample was tested for 20 minutes under a load of 5 N. The Microhardness of the first deposited layer increased from the substrate, and reached 1000-1200 HV₀.₃ at its surface, and was approximately 6 times higher than the average microhardness of the base material. The microhardness of the second and third layers also increased from 1200-1400 to 1500-1600 HV₀.₃. The Coating obtained at a laser power of 1500 W had the lowest coefficient of friction of 0.55 and the wear rate (2.15±0.31) ×10⁻⁷ mm²·(N·m)⁻¹.

The aim of this work is to determine the tribological characteristics of multi component coatings with the addition of nano-powder of tungsten carbide.

2. Materials and equipment
The laser system of the IMASH RAN collective center was used in experimental studies. The samples were made of 40Kh steel with dimensions of 15×20×70 mm. Powders based on Nickel PR-NiKh13SiB3 and cobalt PR-CoKh30Ni6WSiB in a ratio of 2:1 with a particle size of 40-150 μm, respectively, were selected for the production of the charge. Nano tungsten carbide powder WC with a particle size of 40-100 nm. The composition of the powders can be represented as (Ni-Cr-B-Si, Co-Cr-W-Ni-B-Si) + WC 5 and 10 vol.%. Slip coatings were applied with a thickness of 0.85-1.0 mm. An aqueous solution of hydroxyethylcellulose was used as the binding material. The radiation power P = 800-1000 W, the processing speed V= 5-10 mm·s⁻¹, and the beam diameter d = 2.5-3.5 mm were chosen as the variable parameters. As an additional factor, we considered scanning a beam with a fixed frequency f=225 Hz. Metallographic studies of deposited coatings were performed on a PMT-3 microhardness meter at a load of 0.98 N, an Altami MET 1C metallographic microscope, and an AM413ML digital microscope. The structure and chemical composition of the deposited layers were studied using a Tescan VEGA 3 SBH scanning electron microscope with an energy-dispersive analysis system using reflected and secondary electron modes. To determine the tribological characteristics of the deposited samples, a test was performed at normal temperature according to the plane (deposited sample) – ring scheme (50KhVA steel, 49-52). The sliding speed and pressure on the sample varied discretely in the range of 0.25-3.0 m·s⁻¹ and 1-5 MPa, respectively. TP22C oil was used as a lubricant.

The radiation power P=700-1000 W, the processing speed V=7-10 mm·s⁻¹, and the beam diameter d=2.5-3.5 mm were chosen as the variable parameters. As an additional factor, we considered beam scanning with a fixed frequency f=225 Hz. To construct mathematical models, the height H and width B of the deposited rollers were considered as the system responses when performing a full factorial experiment (FFE). Since the range of variable parameters has a rather narrow range, a linear dependence of changes in the experimental factors is assumed. Table 1 shows the levels of experimental factors. Since FFE 2³ was performed, the number of experiments was 8 for each series.

The regression equation has the form:
\[ y = b_0 + b_1x_1 + b_2x_2 + b_3x_3 + b_{13}x_1x_3 + b_{23}x_2x_3 + b_{123}x_1x_2x_3 \]  \hspace{1cm} (1)

Where \( y \) – system response; \( x_i \) – is the levels of factors; \( b \) – coefficients of the regression equation.

**Table 1. Levels of experiment factors.**

| Factor \( z_i \) | Upper level of factor \( z_i^+ \) | Lower level of factor \( z_i^- \) | Center of the plan \( z_i^0 \) | Variation Interval \( \lambda_i \) | Dependence of the encoded variable on the natural |
|------------------|----------------------------------|----------------------------------|--------------------------|--------------------------|------------------------------------------|
| \( P \) (W)      | 1000                             | 700                              | 850                      | 150                      | \( x_1 = \frac{P_i - 850}{150} \)          |
| \( V \) (mm·s\(^{-1}\)) | 9                                | 7                                | 8                        | 1                        | \( x_1 = V_i - 8 \)                        |
| \( d \) (mm)     | 3.5                              | 2.5                              | 3.0                      | 0.5                      | \( x_i = \frac{d_i - 3}{0.5} \)            |

### 3. Results of experiments

Laser surfacing of samples was performed under optimal conditions with a defocused beam and with transverse beam vibrations normal to the laser processing speed vector. Figure 1 (a, b) shows microsections of deposited tracks with a 10 vol. % content of nano-tungsten carbide with dimensions of 0.87×2.34 mm, hardness (980-1040 HV), and 0.83×3.56 mm - (1030-1120 HV), obtained by an unfocused beam and a scanning beam with a frequency of 225 Hz, respectively. The penetration zone of the substrate during processing with a defocused beam and a scanning beam was 189 and 86 \( \mu \)m, respectively. The cross sectional area of a single deposited layer when scanning the beam is 1.57 times larger than when surfacing with an unfocused beam.

**Figure 1.** Microstructures of deposited coatings containing 10 vol. % nano-tungsten carbide: a-defocused beam surfacing; b-scanning beam surfacing.

The equation for determining the height of the roller without scanning, \( H \) has the form:

\[ H = 0.925625 + 0.156875x_1 - 0.119375x_2 + 0.115625x_3 - 0.048125x_1x_2 + 0.031875x_1x_3 - 0.054375x_2x_3 \]  \hspace{1cm} (2)

The height of the roller when welding with transverse oscillation of the beam, \( H_s \):
\[ H_s = 0.93375 + 0.09625x_1 - 0.02625x_2 + 0.02375x_3 + 0.01625x_1x_3 - 0.07625x_2x_3 - 0.04875x_1x_2x_3 \]  

Width of the deposited roller without scanning the beam, \( B \):

\[ B = 1.7125 + 0.235x_1 - 0.15x_2 + 0.0475x_3 - 0.1075x_1x_2 - 0.045x_1x_3 - 0.065x_2x_3 \]  

Width of the deposited rollers with transverse vibrations of the \( Bs \) beam:

\[ Bs = 3.61625 + 0.35875x_1 - 0.37875x_2 + 0.07125x_3 - 0.03125x_1x_2 + 0.21375x_1x_3 + 0.15625x_2x_3 \]  

The regression equations (2-5) are used for calculations that are compared with the results of the experiment. The calculated values differ from the actual values of the depth and width of the quenching zones by no more than 3.14%.

For dependencies of type \( H (P, V), B (P, V) \), comparative surfaces are constructed using the MsExcel program (figure 2) with a spot diameter of 2.5 mm.

\[ \text{Figure 2. Dependence of the height (a, b) and width (c, d) of the deposited rollers on the speed and power of processing with a beam diameter of 2.5 mm: (a, c) – with a defocused beam, (b, d) are scanning beam.} \]
The radiation power has a predominant influence on the geometric parameters of the deposited rollers. With increasing power, the width and height of the surfaced tracks grow. As the speed of movement increases, the depth and width of the rollers decreases. With increasing defocusing of laser radiation, the depth and width of the rollers increases.

One of the most important characteristics of friction units is the low coefficient of friction, which affects the performance of fuel and lubricants in the operation of transport equipment. As a rule, the friction pair with a low coefficient of friction has a high load binding.

One of the most important characteristics of friction units is the low coefficient of friction, which affects the performance of fuel and lubricants in the operation of transport equipment. As a rule, the friction pair with a low coefficient of friction has a high load binding. The dependence of the friction coefficients of 40Kh steel in the improved and hardened state and the deposited coatings is shown in figure 3.

![Graph](a)

![Graph](b)

**Figure 3.** Dependence of friction coefficients on pressure (a) and sliding speed (b): 1 – 40Kh steel (250-296HV), 2 – 40Kh steel (450-510HV), 3 – Ni-Cr-B-Si, Co-Cr-W-Ni-B-Si (750-860HV), 4 – (Ni-Cr-B-Si, Co-Cr-W-Ni-B-Si) + 5 WC vol.% (850-970HV), (Ni-CR-B-Si, co-CR-W-NI-b-S1) + 10 WC vol.% (890-1270HV).
As the load increases from 1.2 to 4.0 MPa on improved and hardened 40Kh steel samples, the coefficient of friction drops from 0.13 and 0.11 to 0.1 and 0.07, respectively. With a further increase in the load for the improved sample, the coefficient of friction increases, and for the hardened one it continues to decrease to 0.048. The coefficient of friction for the multi component coating varies within 0.03-0.043. The Minimum coefficient of friction 0.01-0.02 was obtained on a coating with additives of 10 vol% WC nano powder. With an increase in the sliding speed from 0.25 to 1.35 m/s\(^{-1}\) under constant load, the coefficient of friction for 40Kh steel decreases from 0.12-0.13 to 0.1-0.11. With a further increase in speed to 1.6 m/s\(^{-1}\), it increases slightly. For deposited coatings in the range of 0.6-1.6 m/s\(^{-1}\), the coefficient of friction increases smoothly.

Figure 4 shows the patterns of changes in the jamming load from the sliding speed. Improved and hardened 40Kh steel samples are inferior to surfaced multicomponent coatings and with the addition of nano-tungsten carbide powder. At a pressure of 5.5 MPa, jamming occurs at a speed of 3-5 times and 0.25-2 times lower for an improved and hardened 40Kh steel sample, compared to surfacing with a multicomponent coating and with additives of 10 W vol.% respectively.

For figure 5 wear rates of 40Kh steel samples with different heat treatment and deposited coatings are shown. Wear resistance, the inverse of the wear intensity, increases for many component coatings by 30 and 25% and 57 and 62% compared to improved and hardened 40Kh steel with an addition of 5 and 10 vol.% to charge nano powder WC respectively.

**Figure 4.** Dependence of the jamming load on the sliding speed: 1 – 40Kh steel (250-296HV), 2 – 40Kh steel (450-510HV), 3 - Ni-Cr-B-Si, Co-Cr-W-Ni-B-Si, 4- (Ni-Cr-B-Si, Co-Cr-W-Ni-B-Si) + 5 WC vol.% (850-970HV), 5 - (Ni-Cr-B-Si, Co-Cr-W-Ni-B-Si) + 10 WC VOL.% (890-1270HV).

**Figure 5.** Wear rates of samples: 1 – 40Kh steel (250-296HV), 2 – 40Kh steel (450-510HV), 3 - Ni-Cr-B-Si, Co-Cr-W-Ni-B-Si 4- (Ni-Cr-B-Si, Co-Cr-W-Ni-B-Si) + 5 WC vol.% (850-970HV), 5 - (Ni-Cr-B-Si, Co-Cr-W-Ni-B-Si) + 10 WC VOL.% (890-1270HV).

**4. Conclusions**

The technology of laser surfacing of multi component coatings with additives of 5 and 10 vol.% nano-tungsten carbide has been developed, decreases the wear resistance of improved and hardened 40Kh steel by 25-62% and the load of jamming up to 5 times at a pressure of 5.5 MPa. Coatings with nano-tungsten carbides have the lowest friction coefficients of 0.01-0.02.
References

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