

# Research on microstructure and wear resistance of coatings obtained by adding nanoparticles of refractory compounds in laser cladding

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**Abstract.** The paper is aimed at research of coatings, which are achieved by means of laser cladding with additives of nanoparticles of high-melting compounds in form of tungsten carbide and tantalum (WC and TaC). In the course of experiment, various ceramic powder concentrations were tested. Main technological characteristics were determined. Power density amounted to 0.68–0.98 MW/cm<sup>2</sup>. During the coating wear resistance measurement, it was discovered that increase in nanopowder concentration extended wear resistance of coating 2–6 times. Wear resistance measurement and wear coefficient calculation were performed using Brinell-Howarth method. The load was 15 N, load time was 10 minutes. Optical metallographic microscope Neophot-30 was used to study microstructure of the deposited coatings. To reveal microstructure of the deposited coatings, the samples were exposed to chemical etching. Elemental composition of the samples was determined by the methods of X-ray microanalysis in testing solution using electron microscope EVO-50 under acceleration voltage 10–20 kV (probe current 5–50 nA) using energy- and wavelength-dispersive spectrometers.

## 1. Introduction

Laser cladding of powder is widely used to recover and produce protective coatings in various fields of mechanical engineering, mining, oil and gas industries. In recent years, scientists work actively to produce coatings with nanopowder additives [1–5]. The work involves such studies as microstructural analysis and wear resistance measuring. It is noted that with the addition of nanoparticles, microstructure is improved and wearing is reduced.

This work represents a comparative analysis of coating microstructures obtained with the addition of tungsten and tantalum carbide nanoparticles. Brinell-Howarth method was used to measure wear resistance. It was found that with increasing nanoceramics concentration, wear resistance of coatings with nano-additives is growing 2–6 times compared to conventional steel substrate.

## 2. Experiment methodology

Experiments were conducted on a C5140 steel substrate. Its chemical composition is shown in Table 1.

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**Table 1.** C5140 chemical composition.

|           | Ni  | C    | Fe | Cr  | Si   |
|-----------|-----|------|----|-----|------|
| Substrate | 0.3 | 0.40 | 97 | 0.9 | 0.20 |

As the main powder, 1559-40 by Höganäs was chosen. Different concentrations of TaC and WC nanopowders (5, 10, 15, and 20 wt.%, respectively) were added to this powder. Powders were premixed to obtain homogeneous distribution of particles, and then the binder, cellulose aqueous solution, was added. This mixture was placed on steel plates with dimensions 60×20×10 mm, and then well dried.

Selection of parameters was carried out with ytterbium 5 kW fiber laser as follows: in the first part of the experiment, process parameters on the substrate without the powder were selected. The following parameters were varied: processing speed, blooming, power of the laser radiation. Substrate surface temperature was measured using an infrared FLIR camera. According to [6], temperature significantly influences content of tungsten carbide in the coating, thus the parameters ensuring surface temperature of 1100°C were selected.

After the first part of the experiment was completed, these parameters were adjusted on already powdered substrate with and without nanoparticles additives. Power densities used in these experiments were 0.68–0.98 MW/cm<sup>2</sup>. Heat input was 7.5 kJ /m.

### 3. Results and discussion

Abrasion testing was carried out using Brinell-Howarth method. The test procedure is shown in figure 1: a rotating rubber disk 1 is pressed against the sample 2, and abrasive (river sand) pours through the feed magazine 4. The load (number 3) is 15 N, exposure time is 10 minutes.

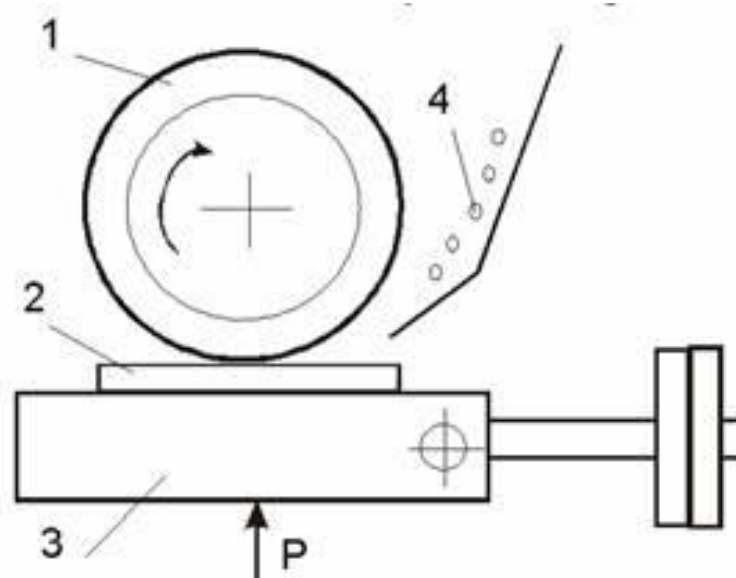


**Figure 1.** Overall schematic of the wearing test according to Brinell-Howarth method.

Figure 2 shows the results of calculation of the wear resistance coefficient  $K$ , obtained at different power densities and different nanopowder concentrations of tantalum carbide and tungsten carbide.

It can be seen in Figure 2 that wear resistance coefficient increases with increasing concentration of ceramic nanoparticles. It was also observed that with an increase of power density, wear resistance decreases, which is because WC and TaC decompose and form secondary carbides or other compounds.

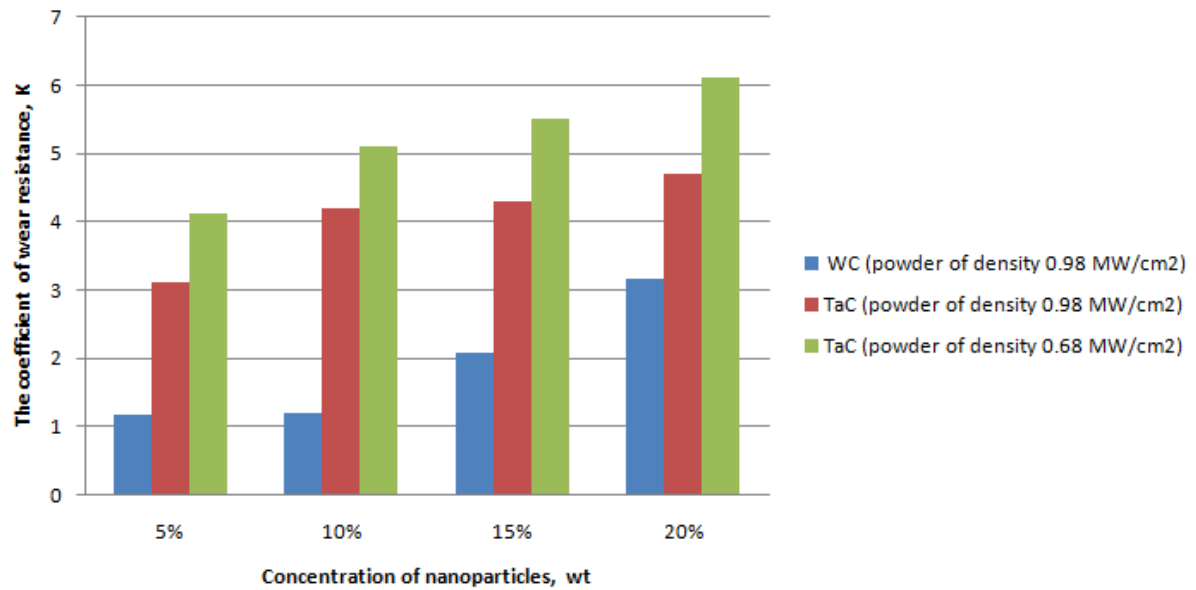


**Figure 2.** Wear resistance coefficient at different concentrations of nanoparticles and different power densities.

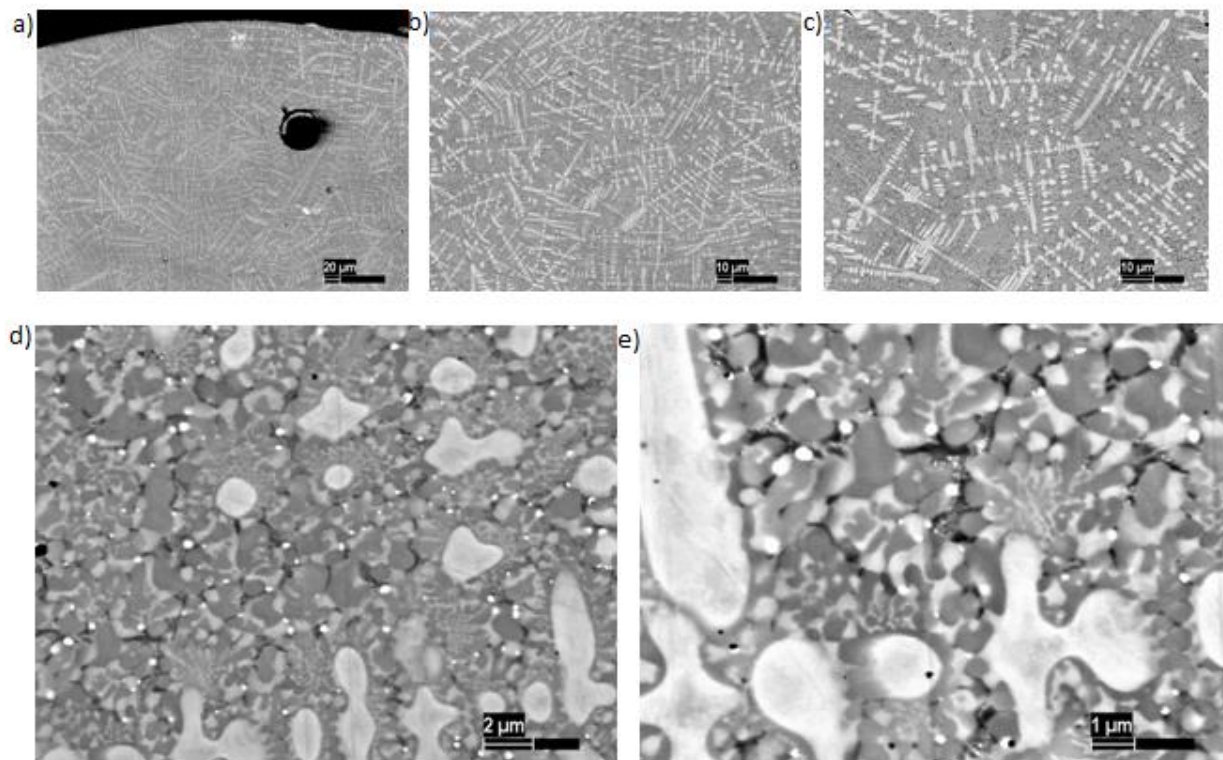


**Figure 3.** Microstructure of the coatings with nano-WC additives (concentration 10%): a) 250x magnification; b) 500x magnification; c) 1000x magnification; d) 2500x magnification; e) 5000x magnification.

Figure 3 shows coating microstructure produced by laser cladding with additives of tungsten carbide nanopowder at different magnifications. There is an acicular structure. In figure 3 (d, e) white

patches are clearly seen, these are nanoparticles of tungsten carbide. The microstructure is fine dispersed, fine-grained because of the content of the nanoparticles in the coating.

**Table 2.** Measurement results of the reflection spectrum of backscattered electrons and chemical composition at each point by laser cladding with additives of nano-W (concentration 7.5%).

| Spectrum                | C    | Si   | Cr   | Fe    | Ni    | W    |
|-------------------------|------|------|------|-------|-------|------|
| Top clad                | 1.97 | 2.74 | 0.44 | 1.48  | 87.52 | 5.85 |
| Boundary clad/substrate | 1.54 | 2.60 | 0.45 | 3.89  | 85.55 | 5.96 |
| Substrate               | -    | -    | 0.12 | 99.02 | -     | -    |

As we can see from the Table 2, tungsten is present in a single track, which is consistent with the spectrum of the backscattered electrons in the top clad, the clad/substrate boundary and the substrate. Exactly at the “coating-substrate” transition boundary tungsten disappears, therefore iron, which is present in the substrate, partially diffuses into the coating body. Cladding boundary is sharp, and the mixing is minimal.

#### 4. Conclusion

Laser cladding deposit was made with powder additives of TaC and WC ceramic nanoparticles. It was revealed that nanopowder additives affect both microstructure and mechanical properties of the coatings, particularly, their wear resistance. The fine-grained, acicular microstructure containing WC nanoparticles between grains was observed. No defects, such as cracks, were detected in the process of cladding deposition.

Wear resistance of the coating is improved 2–6 times compared to the ordinary steel, which also indicates the effect that nanoparticles produce on its physical and mechanical properties. During the process of cladding deposition, temperature did not exceed 1100°C, ensuring the WC and TaC nanoparticles presence in the coating.

The power density ranged from 0.68 to 0.98 MW/cm<sup>2</sup>, and the heat input was 7.5 kJ /m.

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