Comparison of WC and (TiW)C in nickel-based alloy coatings prepared by laser cladding

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Abstract. For wear demanding applications, the coatings, consisting of WC in the nickel-based alloy are often used due to their excellent properties. Nevertheless, there are still limits of these coatings, mainly deterioration of tungsten carbide due to heat load during laser cladding. The suppress the limits, a new type of coating material, consisting of the (TiW)C\textsubscript{1-x} in nickel-based alloy, was designed. The goal of this study is to compare the microstructure and mechanical properties of new (TiW)C\textsubscript{1-x} based coating with a usual WC-based coating to confirm its improved behaviour.

1 Introduction
Laser cladding is a technology capable of producing compact functional coatings from a variety of materials. For example, it is widely used for the production of a wear resistant layer using the metal matrix composites (MMCs). These materials excel in their high wear resistance due to the tough matrix and hard reinforcing particles [1].

Among MMCs, the combination of Ni-based alloy and tungsten carbide is widely used. The role of laser cladding processing parameters as well as the role of powder composition on the final appearance of tungsten carbides in the coating and thus on its final functional properties as is hardness was analyzed in various studies [2–6]. However, tungsten carbide also has some disadvantages which can limit its use. Tungsten carbide suffers from extensive degradation during laser cladding process and has inferior thermodynamic stability compared to many other carbides [7]. New types of carbides and MMCs coatings are being developed to overcome the limitations associated with tungsten carbide based coatings [7].
The aim of this study is to compare microstructure and mechanical properties of the new experimental (TiW)C\textsubscript{1-x} based coating with previously tested commercially available WC-based coating. Both coatings were deposited by 5kW solid state disc laser Trumpf TruDisk.

2 Experimental procedure

2.1 Feedstock powders
For the WC based coating, the commercially available feedstock powder from the Oerlikon Metco company designated as MetcoClad 52052 was used. The powder is composed of 60 wt% of WC spherical particles blended with 40 wt% of gas atomized NiCrBSi (8.0Cr3.5Si1.6B0.3C Ni bal.) particles. The particle size distribution lies between 45-106 µm. The WC was manufactured in a
unique way, resulting in a non-acicular shape with higher hardness than conventional fused and crushed WC [8].

The new experimental powder from the Oerlikon Metco company is composed of 60 wt% of angularly shaped (TiW)C_{1-x} carbides blended with the same Ni self-fluxing alloy as in the previous case. The density of (TiW)C_{1-x} carbide is 10.1 g/cm³, lower than the density of WC which is 15.63 g/cm³ [7]. This means, that the volume percentage of carbides in the new powder is higher than in MetcoClad 52052.

2.2 Laser cladding process and parameters
Laser cladding was executed using the solid state laser Trumpf TruDisk 8002 with Precitec coaxial 4-way cladding head YC52.

From the experimental powder, two variants of the coatings were cladded using different heat input. The laser cladding process parameters were chosen as follows: powder feed rate $F = 540$ mg/s, process speed $S = 8.3$ mm/s and laser power for variant 1 $P = 2400$ W and variant 2 $P = 1400$ W.

For the comparison, it was chosen the tungsten carbide based coating cladded in the previous study. The processing parameters for this coating were as follows: $F = 475$ mg/s, $S = 8.3$ mm/s, $P = 3000$ W. The overlapping ratio was 50% of the single bead width.

The coatings were deposited onto plates of carbon steel (EN10083 2: C45) with dimensions $100 \times 100 \times 20$ mm to ensure sufficient heat dissipation. Substrates were pre-heated to 350 °C prior to deposition to avoid cracking of the coating due to the high thermal gradient. After the deposition, the samples were left to cool down at room temperature.

2.3 Characterization
The microstructure was evaluated on the coatings’ cross-sections (ground and polished by automatic Leco grinding and polishing equipment) using digital optical microscope HIROX KH 7700. The thickness of the coating was measured as the minimal distance from the interface of the coating and the substrate to the top of the coating. It was averaged from 5 measurements. The microhardness HV1 was evaluated on the coatings’ cross-sections. For each coating, the matrix of indents’ locations (6 x 6) was designed to cover the area of the two overlapping tracks.

3 Results and discussion
3.1 Structure of the coatings
The thickness of the (TiW)C_{1-x} based coating is similar for both variants, namely 2450 µm for the variant 1 with high heat input and 2588 µm for the variant 2. The structure of the (TiW)C_{1-x} coatings on the cross sections longitudinal and traverse to the direction of cladding is shown in figure 1.

The structure of both variants of the coating differs significantly. In the coating cladded with high heat input marked as variant 1, high amount of undissolved carbide particles is near the coating surface and near the interface with the substrate. In the middle of the coating, the majority of carbide particles is dissolved in the matrix and solidified again. The reason for different carbide dissolution in the coating is the speed of solidification. The surface and interface area are cooled more effectively than the middle of the coating and thus solidified earlier. The detailed microstructure in these three areas is shown in figure 2.
Figure 1. The cross-section of the (TiW)\textsubscript{C}\textsubscript{1-x} based coatings, variant 1 with high heat input: a) longitudinal and b) transverse; variant 2 with low heat input: c) longitudinal and d) transverse.

On the contrary, in the variant 2 of the coating, cladded with lower heat input, the majority of the carbides is preserved undissolved through the whole coating. The reason is that thanks to lower heat input, the temperature is not as high as in variant 1 and the whole coating solidifies more rapidly. The detailed microstructure of the coating is again shown in figure 2. However, the variant 2 of the coating contain many imperfections – cracks and big pores up to size 1 mm appearing primarily on the interface with the substrate. The interface of the coating with the substrate, in this case, is insufficiently melted and it is not as homogenous as in variant 1. This is due to low heat input, the energy is insufficient to effectively melt higher volume of the substrate and to heat the melt pool to a higher temperature. Due to rapid solidification, the gas bounded on powder surface does not have sufficient time to escape the melt pool and creates pores. The imperfections in the coating can be clearly visible on the cross-section on figure 1 c) and d) and on figure 2 f).
Figure 2. Detailed microstructure of the (TiW)C_{1-x} based coatings, variant 1: a) top, b) middle, c) interface with the substrate; and variant 2: d) top, e) middle, f) interface with the substrate.

For the comparison, the microstructure of the WC based coating is shown in figure 3. Similarly to (TiW)C_{1-x} coating variant 1, more undissolved carbide particles remain near the coating surface and interface with the substrate. However, the majority of the carbides are dissolved in the matrix and the amount of undissolved WC particles is significantly lower than in above-presented coatings. The reason is that tungsten carbide has inferior thermodynamic stability. The second reason is that this coating contains lower volume percentage of carbide particles that the new experimental one. The carbides with matrix are mixed in the same weight ratio but the tungsten carbide has a higher
density. The dissolution of carbide would significantly affect the final coating mechanical properties.

![Figure 3](image)

**Figure 3.** The microstructure of WC based coating: a) overall transverse, and details b) top, c) middle and d) interface with the substrate.

### 3.2 Hardness

The dependence of the hardness HV1 on the distance from the interface with the substrate for all three coating is presented in figure 4.

![Figure 4](image)

**Figure 4.** Microhardness depth profiles of tested coatings.
The hardness of the new experimental coating is significantly higher than the WC based coating. The average hardness HV1 of (TiW)C\textsubscript{1-x} based coatings is in the range 1070 – 2370 and for the WC based coating only 600 – 640. The main reason is the dissolution of the carbide particles. The hardness profile reflects the amount of undissolved particles. The role of carbide dissolution on the hardness of WC based coating is discussed in a previous study [2]. The second reason is the new carbide itself has a higher hardness than the tungsten carbide. The average microhardness HV0.05 of WC is only 2200 and of (TiW)C\textsubscript{1-x} is 2818 [7].

4 Conclusion
In this study, the coatings from a new experimental powder containing (TiW)C\textsubscript{1-x} in Ni alloy were created by laser cladding technology. The new coatings were compared to the coating cladded from a commercially available powder containing WC in Ni alloy.

In the new experimental (TiW)C\textsubscript{1-x} based coating, a high amount of carbide particles remain undissolved compared to the WC based coating. The dissolution also differs for the two variants of the (TiW)C\textsubscript{1-x} coating. With high heat input, the undissolved particles are mainly near the surface and interface and in the middle, more carbides are dissolved in the matrix. In the variant cladded with low heat input, the carbide particles remain undissolved through the whole coating.

The hardness HV1 of the new coating is in the range 1070 – 2370 and is much higher than the hardness of WC based coating. The hardness depth profile reflects the dissolution of the carbides. The new coating is very promising and more detailed analysis of mechanical properties such as wear resistance is underway.

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