THE INFLUENCE OF PROCESSING PARAMETERS ON THE MICROSTRUCTURE OF WC-NiCrBSi LASER CLAD COATINGS

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Abstract

Laser cladding is a progressive technology enabling to deposit coatings in thickness higher than 1 mm. In comparison with the conventional overwelds it offers the advantage of thinner heat-affected zone in the substrate material and lower and better controlled inner residual stress and related deformation. Compare to thermal sprayed coatings, it provides the metallurgical bonding to the substrate and fully dense coating microstructure with zero porosity, enabling the full corrosion protection of substrate. The range of materials deposited by laser cladding is limited to metals and its alloy due to the principle of technology, requiring the simultaneous melting of substrate surface layer and added coating materials. To improve the wear resistance, the hard particles such as carbides are added to the feedstock powder. During deposition process, the kinetics of melting and solidification of both metal and carbide particles are controlled by used technological parameters of laser. In the paper, the influence of deposition parameters on the geometrical characteristics and microstructure of WC-NiCrBSi laser clad coating is presented with attention paid namely to the hard particles decomposition and its influence on the measured hardness.

Keywords: WC-NiCrBSi, laser clad, dilution, laser beam scanning speed, carbide dissolution

1. INTRODUCTION

Metal matrix composites (MMCs) materials are well known for their high wear resistance thanks to combination of tough matrix and hard reinforcement particles. Usually, Co or Ni-based alloys are used as a matrix material, while WC, CrC or TiC are the most common hard particles [1]. In thermal spray MMCs are widely used. Namely HVOF (High Velocity Oxygen Fuel) sprayed WC-17%Co and Cr_3C_2-25%NiCr are considered as typical solution for application resisting wear, corrosion or high temperature [2,3]. Nevertheless, for the most demanded components, the adhesion and density of HVOF sprayed coatings might not be sufficient. In these cases, the laser clad technology can offer an alternative of fully dense coatings that are metallurgicaly bonded to the substrate.

Compare to the thermal spray materials, the commercially available feedstock material selection is rather limited. The high shrinkage residual stress arising during solidification of melting pool leads in many case to cracking. That is why metal alloy coatings with better resistance to cracking are the most used laser clad materials. The reinforcement of metal alloy with hard ceramic particles increases not only the coatings wear resistance, but also its susceptibility to cracking.

From the group of MMCs, namely the combination of WC and Ni matrix has been studied in terms of WC content, size and shape distribution [4, 5]. Lately, the attention was paid to the self-fluxing NiCrBSi alloy reinforced by WC particles. The susceptibility to cracking, microstructure, hardness and wear resistance of WC-NiCrBSi laser clad coatings dependence on WC content in the WC-NiCrBSi blends was the main interest [6, 7, 8].

As the cladding process is strongly dependent on the characteristic of laser source, the obtained coatings differs according to the type of laser and used laser parameters. The number of factors involved, regarding both the material of substrate and feedstock as well as the laser beam characteristics make the comparison between the reported results rather difficult. Even if first attempt to describe the dependence of laser clad coatings microstructure on processing parameters was already done, there is still a lot of uncertainty that has to be clarified.

In this paper, the processability, microstructure and microhardness of WC-40%NiCrBSi coating deposited by 5kW solid state laser TRUMPF TRUDISK 8002 is studied independence on processing parameters, namely scanning speed.

2. EXPERIMENTAL

2.1. Feedstock powder

The commercially available feedstock powder from Oerlicon Metco company designated as MetcoClad 52052 were used for cladding. Its chemical composition is shown in the **Table 1**. The particle size distribution lays between 45-106 μm. The powder is blended from two kinds of particles NiCrBiSi gas atomized particles and spherical WC particles. The WC was manufactured in a unique way, resulting in non-acicular shape with higher hardness than conventional fused and crushed WC [9]. The powder size distribution as well as the cross section can be seen in the **Figure 1**.The detailed study of NiCrBSi HVOF sprayed and laser remelted coatings were already presented by authors [10]; nevertheless the chemical composition of evaluated powder differs from that studied in this paper.

Table 1 The chemical composition WC-40%NiCrBSi powder [9]

Hard phase 60%		Metal matrix 40%				
W	C	Ni	Cr	Si	B	C
balance	3.8	balance	8.0	3.5	1.6	0.3

The composition of powder was verified by SEM with EDX measurement (**Figure 1**). The powder blend compose from light particles with high amount of W (WC particles) and dark grey particles with major content of Ni (NiCrBSi).

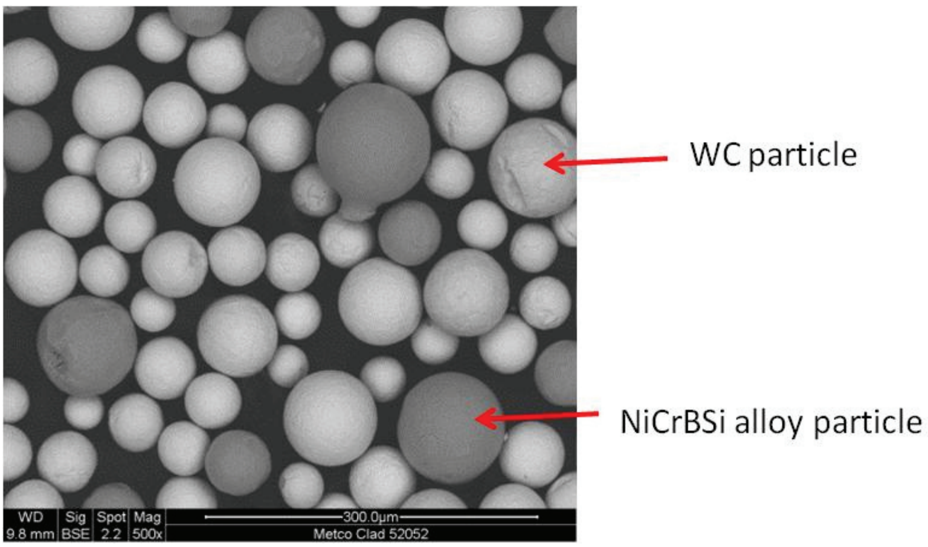

Figure 1 MetcoClad 52052 powder

2.2. Laser cladding process and parameters

Laser cladding was realized by the Solid state laser Trumpf TruDisk 8002 with Precitec coaxial 4-way cladding head YC52. The experiment was designed to evaluate the influence of laser parameters on the geometrical parameters of created beads and on the microstructure of MMC material. The designed laser parameters are summarized in **Table 2**. For all parameters, the spot size was kept constant 3.3 mm.

Table 2 The chemical composition WC-40%NiCrBSi powder

Param. no.	Power [W]	Scanning velocity [cm/min]	Feed rate [g/min]	Feed rate [g/cm]	Specific energy [J/mm]	Mass specific energy [J/g]
a	3000	15	28	1.86	1200	6428
b	3000	30	28	0.93	600	6428
c	3000	50	28	0.56	360	6428
d	3000	75	28	0.37	240	6428
e	3000	100	28	0.28	180	6428

During the experiment, only scanning velocity varied, while laser power was kept constant, as well as the powder feed rate per minute. The specific energy related to irradiated area decreased with increasing scanning speed, as well as the amount of powder per square. Such design enables to keep the mass specific energy, related to the amount of WC-NiCrBSi powder constant.

No pre-heating of the substrate was used for these experiments to avoid influencing the process by further heating. In the real cladding process, the substrate pre-heating is necessary to avoid cracking of the coating during fast cooling. The steel substrate (ČSN 12 050) was used with dimensions (100 x 200x 10 mm) to ensure sufficient and similar heat dissipation for all experimental beads.

2.3. Single laser clad tracks analyses

Single clad tracks were evaluated by optical 3D digital microscope HIROX KH7700. The geometrical characteristics were measured [11]: the clad height H, depth b, width W and angle between the substrate surface and the clad. The combined parameters were calculated: dilution ($D=b/(h+b)$), feed rate per unit length F/S and parameter $(PS/F)^{1/2}$.

The profile of microhardness HV1 was measured on the single clad cross sections to evaluate the influence of both dilution and carbide decomposition on the hardness. The measurement was provided in the middle of clad track, keeping the constant distance 150µm between each indent.

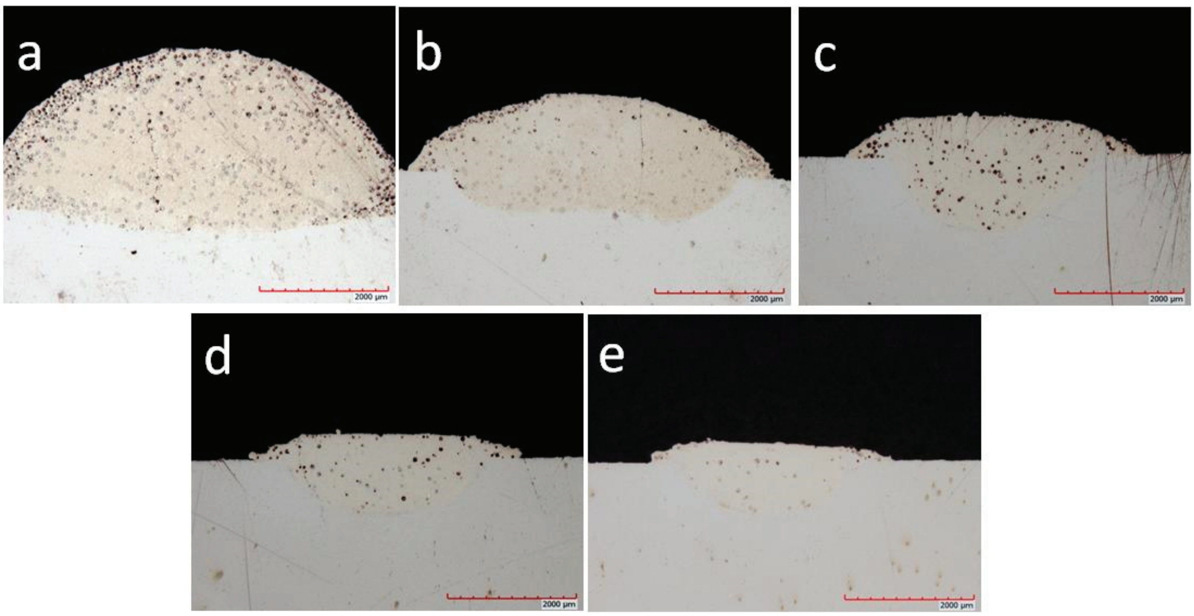

Figure 2 Cross section of single laser clads, parameters a-e

3. RESULTS AND DISCUSSION

In the **Figure 3**, the cross sections of single laser tracks are shown. It can be seen, that the cross amount of cladded material decreased with increasing scanning speed. Such result was expected due to the decreasing specific energy and feeding rate per cm. The dependencies between measured geometrical characteristics and calculated combined parameters, describing the laser process can be seen the **Figure 3**. In agreement with detailed analyses of Ocelík [12], the strong dependence between the laser clad height and feed rate per meter was found (**Figure 3a**). The dilution was expressed in dependence on the combined parameter including laser power, scanning speed and powder feed rate (**Figure 3b**). Dilution does not follow the linear dependence on the parameter, suggesting the threshold in processing window. To create the pore-free coating by overlapping the single clad tracks, the clad the contact angle higher than 100° and dilution in the range of 5-30% should be chosen [12]. In the case of laser clads evaluated in this study, the parameters b with contact angle 127°and 35% dilution are the most suitable. Overlapping the laser tracks, the dilution of coating will decrease due to the consumption of the part of the energy to melt the foregoing laser track.

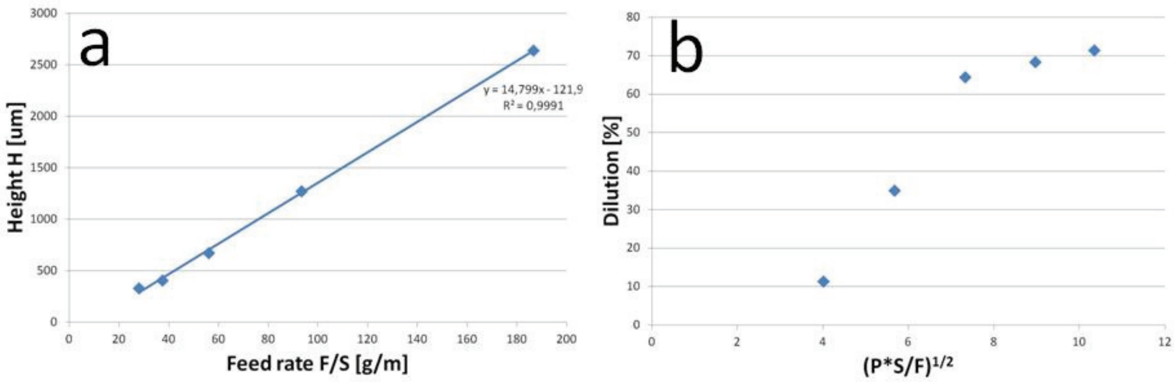

Figure 3 Dependencies between geometrical characteristics and combined laser parameters

The negative influence of dilution on the hardness of deposited material is demonstrated in the **Figure 4**. Hardness of single laser clad, deposited by parameters **a** with low dilution, is higher and more uniform across the clad cross section, the laser clad e is much lower. Two different causes of single laser clad hardness variation in dependence on used parameters can be identified: i) dilution of substrate material into the clad and ii) microstructure differences in consequence of variation in solidification kinetics and level of WC particle dissolution into the NiCrBSi matrix.

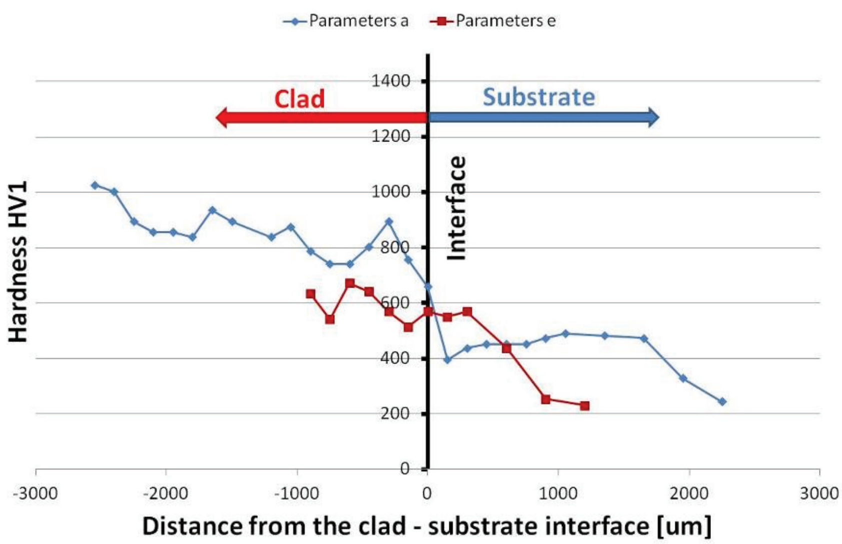

Figure 4 Hardness depth profile of laser clad deposited by parameters **a** and **e**

The microstructure of the laser clads are rather difficult to describe. The dilution has to be taken into account, as well as the presence of 60%WC particles, which are not all melted and dissolute to the matrix. Depending on the deposition parameters, the level of carbides dissolution differs significantly (**Figure 5**). Moreover, the microstructure gradually changes across the laser clad height, as the solidification rate is not constant. Some authors reported the sinking-in of carbides to the bottom of molten pool during cladding due to its higher density, resulting in their non-homogenous distribution [7, 13, 14]. No such effect was observed in this study.

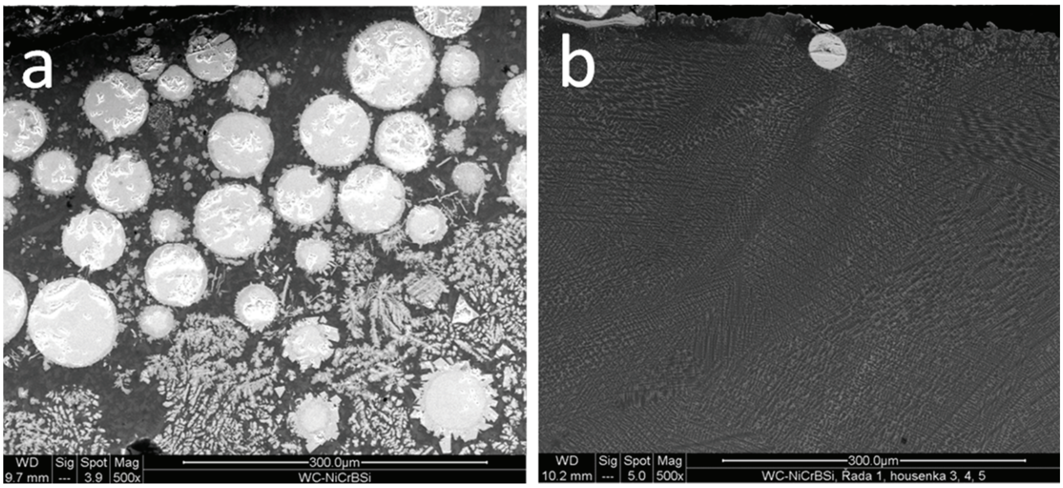

Figure 5 Microstructure of laser clad deposited by a) parameters **a**; b) parameters **e**

4. CONCLUSION

The shape, hardness and microstructure of single laser tracks was studied independence on laser beam scanning speed. According to the expectation, the amount of deposited material increase with decreasing scanning velocity. The lowest scanning velocity and related highest specific energy didn't led to the highest, but on the contrary due to the sufficient amount of powder material to the lowest dilution. Moreover, the carbide dissolution was observed to be the lowest for the lowest used scanning velocity. Based on the presented shape and microstructure analysis, the parameters b was chosen as the most suitable for deposition of coating by overlapping of laser tracks.

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