STUDY OF PROPERTIES OF LAYERS DEPOSITED WITH LASER BY USE OF POWDER FILLERS CONTAINING DIBORIDES





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ABSTRACT

Laser surfacing with hard metal powders presents a new and significant alternative of surfacing thin layers to arc processes as plasma arc and thermal spraying employing the high-temperature and/or high-velocity processes. Laser features some advantages over both these methods. Existing research works and some industrial application of laser surfacing with NiCrSiB-based powders with hardness up to 62 HRC and with additions of carbides, mainly WC, have shown the vitality of this surfacing technology. However, there is still lack of knowledge regarding the applications and properties of powders fabricated especially for laser surfacing. One of these experiments is the subject of this contribution, where the laser weld deposits fabricated with powders composed of powder mixture based on NiCrSiB as a matrix with the CrB_2 – TiB_2 powder as the reinforcing phase were applied.

IIW-Thesaurus keywords: *Laser surfacing; Mechanical properties; Powder; Reference lists; Surfacing.*

1 INTRODUCTION

Laser surfacing is first of all a high-temperature process with temperatures allowing to melt even hard-to-melt metals or alloys or ceramic materials but at the same time it also employs very short heating times in the order of several milliseconds or seconds [1, 2].

This allows to achieve very specific metallurgical processes, both within the weld deposit proper and on the weld overlay – substrate boundary, and also closely below this boundary in the substrate material.

Doc. IIW-1911-08 (ex-doc. IV-948r1-07) recommended for publication by Commission IV “Power Beam Processes”.

The mentioned process allows also to utilize more technological variants for the interaction of surfaced powder with the substrate, for example by powder deposition on the substrate surface closely ahead the heat source or simultaneously with it, either by an independent feed, for example by blowing, jolting etc. directly in the point of beam impingement on substrate material. The laser beam may be hereby more or less defocussed or scanned on the surface, which makes possible to dose the laser power with a high efficiency and accuracy on small, as well as on large, surface areas [3, 4, 5].

Such a process characteristic points out to vast possibilities of varying the technology of laser surfacing with the aim to achieve extremely thin or medium weld deposit thicknesses. Moreover, minimum degree of dilution of the surfaced material with the substrate is observed, while many weld overlays show the character of diffusion bond with the substrate without any dilution, similarly as in the case of brazing [6, 7].

Adherence of such weld deposits with the substrate material is by an order higher than in the case of thermal spraying and it corresponds to the medium strength steel. One of the most excellent characteristics of laser surfacing is minimum distortion given by very thin deposited layer with a steep thermal gradient.

These factors are in significant contrast with the characteristics of others, otherwise comparable surfacing technologies, including high-temperature and high-velocity spraying. The developed and industrially used powders for thermal spraying from renowned manufactures were employed with very good results.

2 EXPERIMENTAL

For experimental programme we used laser surfacing technology where the filler material was fed to the surfacing point during surfacing [1, 2, 6].

For the study of layers fabricated by the suggested method of laser surfacing we have used:

– industrial gas CO_2-laser from Ferranti Photonics Ltd., FWC Inc. Bratislava,

– as a substrate – base metal – the low carbon S235 JRG1 (11 373) steel was applied in 10 mm thickness in form of plates 100 x 100 mm in size,

- as a filler material the CS 52 powder and the powder mixture CS 52 + 30 %(CrB_2-TiB_2) was used.

The chemical composition of these powders is given in Tables 1 and 2.

Assessment of layer properties

To assess the quality of deposited layers, the following methods were selected:

– metallographical study of soundness and structure of layers on cross sections from the fabricated samples,

– micro hardness measurement,

– measurement of abrasive wear resistance. The test is standardized according to STN 01 5084. The principle of test consists in wear of the test piece with a grinding canvas [8],

– topography of sample surface – observing the surface prior and after the abrasive wear test.

3 EXPERIMENTAL RESULTS

The aim of experimental programme was to find out the feasibility of the selected technology of laser surfacing with addition of powder material directly into the process from the viewpoint of abrasive wear resistance.

Table 2 – Chemical composition of filler powder type CrB_2-TiB_2 (reinforcing phase)

Chem. element	C	Si	Cr	Ni	B	Ti*
Weight. [%]	0.9	2.2	7	2.3	2.5	2.5
* Fe balance.						

3.1 Characteristic of TiB_2 – CrB_2 powder particles

The diboride powder comes from the Russian Federation, the Institute of Macro kinetics of the Russian Academy. Based on the values from equilibrium diagrams we can state that the Ti and Cr diborides have very high melting points, whereas it is 3 225 °C for TiB_2 and 2 200 °C for CrB_2.These, together with micro hardness values 3 370 HV for TiB_2 and 2 100 HV for CrB_2 create the set of properties which give a good precondition for their stability in the process of laser surfacing as well as the potential for improving the tribological properties of weld overlay.

SEM observation of powder (Figure 1) has shown that the powder consists of different particles varying in size from several μm to approximately 100 μm. The particles have prevailingly angular shape and they often occur also with smooth cleavage areas, which might suggest that the powder was prepared by grinding or crushing.

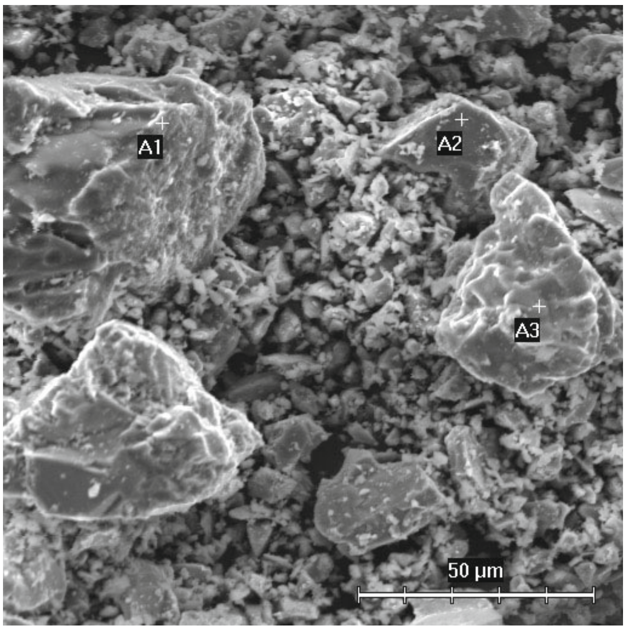

Figure 1 – Sample of diboride powder used for laser weld overlays [3, 5, 9]

Table 1 – Chemical composition of CS 52 powder (matrix)

Chem. element	C	Cr	Si	B	Fe	Al	Ni
weight [%]	max. 0.50	13.65	3.31	2.96	max. 5.0	max. 1.0	balance

Table 3 – Chemical composition measured in the marked points in Figure 1

Point of analysis	Chemical composition [wt. %]					
	Al	Si	Ti	Cr	Ni	Cu
A1	6.75	3.82	9.35	74.39	4.34	1.35
A2	3.26	1.51	2.23	90.74	0.84	1.42
A3	9.21	2.70	27.89	50.47	8.14	1.60

The energy-dispersion analysis has shown that the powders have different chemical composition. Table 3 shows the results of semi-quantitative analysis of presence of the most significant metallic elements.

Regarding high absorption of X-ray radiation by boron, its content in the studied powders was not determined. In spite of that the results suggest that the supplied diborides are not the stechiometric compounds but besides the Ti and Cr they contain also other elements, mainly Al, Si, Ni, Cu eventually also Fe. The great particles consist prevailingly of Cr and Ti, and in the small particles we encountered also higher content of Al and Ni.

The present and supposed elements may form very diverse phases reaching from the most different borides and carbides up to aluminides, silicides and other intermetallic compounds [9,10].

3.2 Structural properties of layers

Macro structural analysis

The macro structural analysis is shown in Figure 2, the bond between the layer and base metal is very good. The boundary was formed partially by the surface melting of the steel and its mixture with surfacing powder. As shown in the figure, the remelting of base metal is very low, which assures low dilution of the weld overlay.

Micro structural analysis

Regarding high absorption of X-ray radiation by boron and carbon the changes in chemical composition of weld overlay were assessed on the basis of changing content of Fe, Ni, Cr and Si.

Observation of structure has shown relatively homogeneous distribution of diboride particles in the samples fabricated of powder mixture, which has proved their stability in laser surfacing process. A typical example is shown in Figure 3.

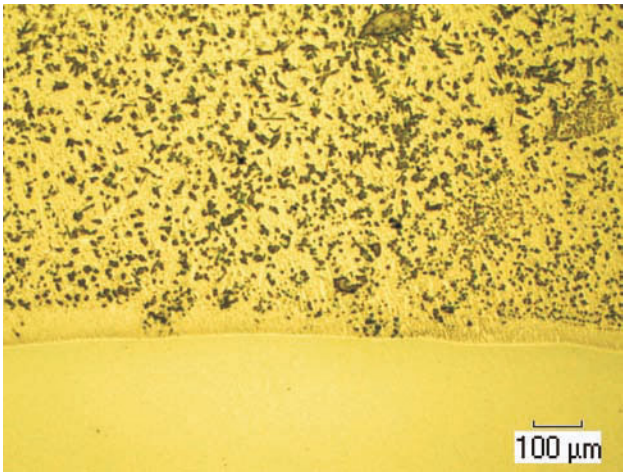

Figure 3 – Structure of a laser weld overlay of CS 52 + 30 % (TiB_2-CrB_2) [9]

Figure 2 – Macrostructure of sample No. 11, CS 52 powder [10]

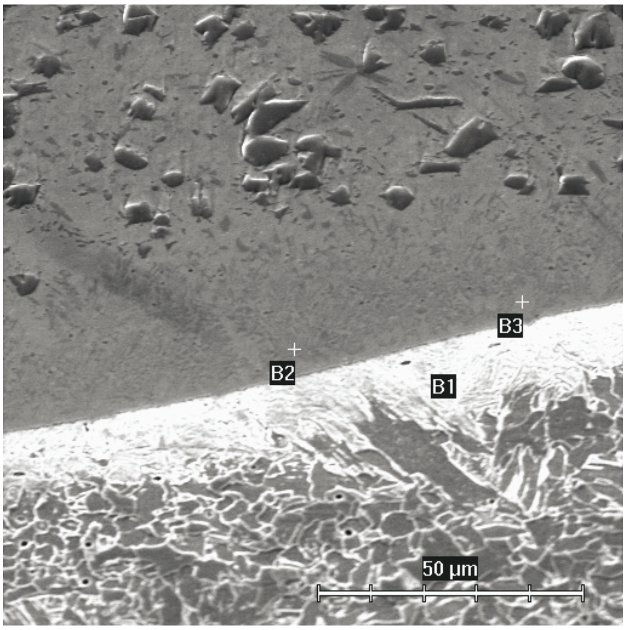

Figure 4 – Structure of boundary between laser weld overlay deposited with TiB_2-CrB_2+CS52 and steel substrate [9]

The bond between the weld deposit and steel substrate is very good (Figure 4), it does not contain any pores nor cracks. This is a boundary formed by partial remelting of thin layer of steel surface and its mixing with surfacing powder type CS 52.

Lower part (Figure 4) shows the steel substrate, which in fact contains only Fe and a small amount of Cr (point B1). In the fusion zone (points B2 and B3), some mixing of CS 52 with Fe matrix occurred to which also chemical composition given in Table 4 corresponds. No diboride particles were observed in this zone, though a slight amount of Ti suggests that dissolving of TiB_2 [9] might occur during surfacing.

Micro hardness test

Micro hardness was measured with hardness meter type Hanneman connected to metallographic microscope type NEOPHOT 2. The structure of laser weld overlay with marked points of hardness measurement is shown in Figure 5. The hardness courses shown in Figure 6 suggest some hardness increase compared to steel substrate, whereas the overlay hardness is not homogeneous but it varies stepwise. In such zones also chromium concentration usually varies. The discrete hardness is thus probably caused by the presence of a hard chromium particle in the measured point. Iron

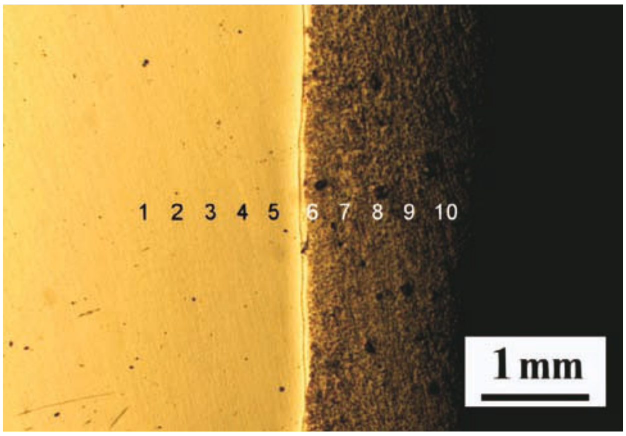

Figure 5 – Structure of laser weld overlay of CS52+30 % (TiB_2-CrB_2) with marked points of analysis [3, 5, 9]

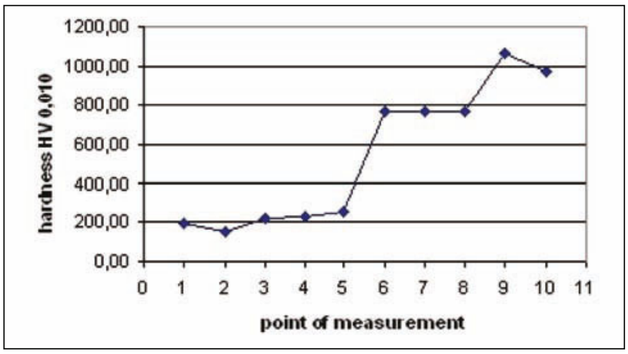

Figure 6 – Course of micro hardness on specimen of TiB_2-CrB_2+CS52 [3, 5, 9]

from the substrate diffuses to weld overlay, while the chromium concentration is rather homogeneous. This would suggest that Ti is dissolved in the nickel matrix of weld overlay [9]

Chemical microanalysis

Analyses of individual elements were performed in points marked from 1 to 10 in Figure 5. The energy-dispersion analysis has shown that the chemical composition of powders is different. Graph in Figure 7 shows the results of semi-quantitative analysis of presence of most significant metallic elements. Regarding high absorption of X-ray radiation by boron, its content in studied powders was not determined [9].

3.3 Test of abrasive wear resistance

Prior to test, the samples and etalons were weighed on an electronic balance with 10^{-3}g accuracy, and after

Table 4 – Chemical composition measured in marked points shown in Figure 4

Point of analysis	Chemical composition [wt. %]					
	Si	S	Ti	Cr	Fe	Ni
B1	0	0	0	0.28	99.72	0
B2	2.96	0	0.36	12.26	51.84	32.57
B3	5.25	0	0.25	6.95	49.07	38.48

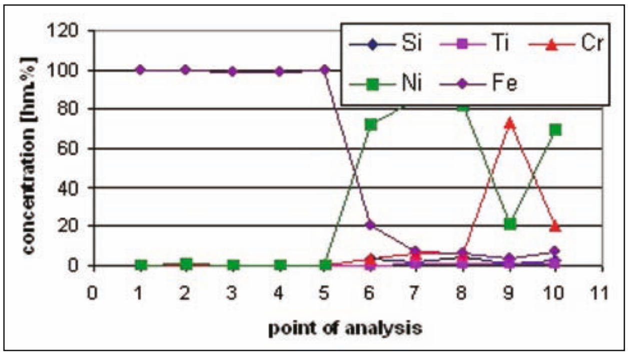

Figure 7 – The course of change in chemical composition at marked points [3, 5, 9]

weighing the sample was fixed in a holder of test equipment (Figure 8) and was loaded with a nominal pressure of 0.25 MPa. The sample was radially shifted over the grinding canvas from the fringe to centre up to its automatic stopping. A new canvas was used for each sample. The etalon value $W_{opz} = 0.3593$ g was attained from the test data of etalon samples after their processing. After test, the samples were again weighed on an electronic balance. From the values measured the weight loss was calculated by use of formula (1) and then also relative abrasive wear resistance [8, 11].

$$\psi_{abr} = \frac{W_{1etalonu}}{W_{2vzorky}} = \frac{W_{het.}}{W_{hvz.}} \cdot \frac{\rho_{vz.}}{\rho_{et.}} = \frac{W_{oet.}}{W_{ovz.}} \qquad (1)$$

where

$W_{oet.}$ = average volume loss of compared samples (etalon) (mm^3),

$W_{ovz.}$ = average volume loss of test samples (mm^3),

$W_{het.}$ $W_{hvz.}$ = average volume loss of compared samples (etalon) or test samples (g) respectively,

$\rho_{et.}$ $\rho_{vz.}$ = density of compared (etalon) or test samples (g/cm^3) respectively.

The results of wear resistance test performed on the samples prepared by the technology of laser surfacing with addition of powder filler materials directly to surfacing process have shown that the relative wear resistance $\psi_{abr.} = 5.871$ of layer made of powder mixture CS52 + 30 %(TiB_2-CrB_2) drastically exceeded the value $\psi_{abr.} = 1.5649$, received in case of CS52 powder application [8, 11].

Figure 8 – Equipment for abrasive wear test [12]

3.4 Surface topography prior to and after wear

Besides the abrasive test proper we also studied the surface topography on the samples with lowest, medium and greatest wear. Figure 9 shows the surface appearance that was equal for all test samples prior to test – initial state.

The best assessment after the test had the sample prepared by use of CS52+30 % (TiB_2-CrB_2) powder, its surface was smooth, with tiny particles of wear products ($\psi_{abr} = 5.87$) Figure 10. Figure 11 ($\psi_{abr} = 1.5649$) shows the plastic displacement at the grooving of sample surface, prepared by use of CS52 powder, with relatively great particles of wear products.

The surface appearance (topography) well correlates with the mass loss and the relative wear resistance ψ_{abr} of the tested samples.

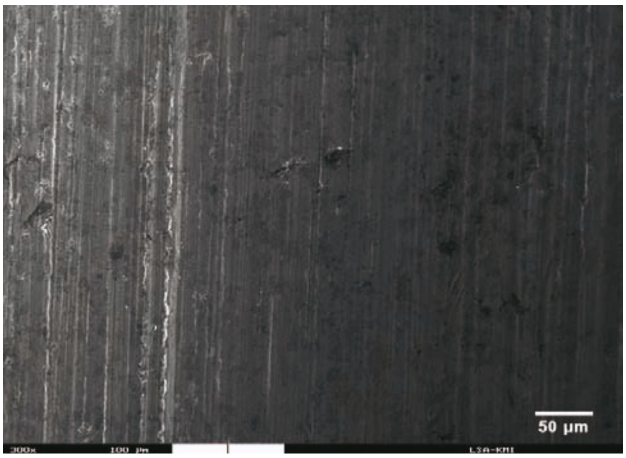

Figure 9 – Topography of sample surface prior to wear resistance test, magnification 300x [13]

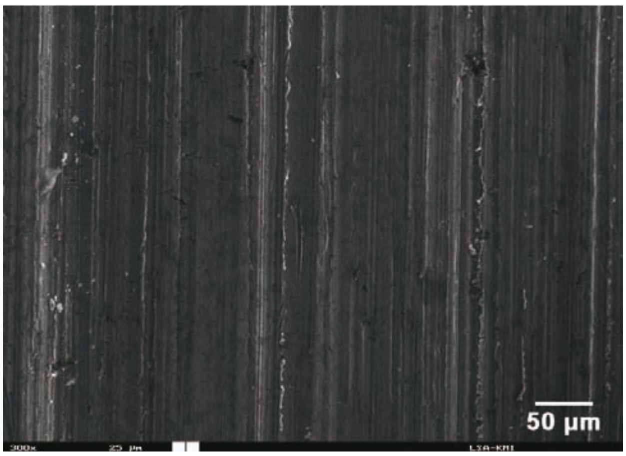

Figure 10 – Surface topography of sample prepared by use of CS52 + 30 % (TiB_2-CrB_2) powder after abrasive wear test, magnification 300x [13]

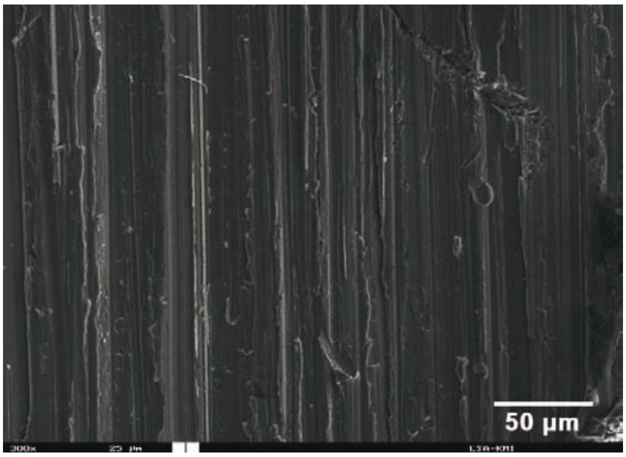

Figure 11 – Surface topography of sample prepared by use of CS52 powder after abrasive wear test, magnification 300x [13]

4 CONCLUSIONS

The CS powder, used for weld overlays is a powder filler based on NiCrBSi, determined mainly for the so-called "cold spraying", which means that the temperature of treated surface would not exceed 250 °C. The powder is suitable for deposition of layers on longer shafts, plungers etc. and the deposited layer is resistant against the abrasive and adhesive wear and also against corrosion [4].

When we add a certain amount of the TiB_2 and CrB_2 particles to this powder, the process of surfacing will change considerably. Melting of this "composite powder" by use of laser beam will induce a number of different reactions which, with high probability, will loose the equilibrium character, owing to very steep gradient of time-temperature cycle. The chemical analysis has shown the presence of new elements in investigated particles of the layer such as Al, Si, Fe, Ni, Cu, which suggests that a great number of different metallic and non-metallic phases have been created in the process of laser surfacing.

On the basis of attained results it can be concluded that a certain portion of initial diboride particles with high Cr (CrB_2) content remains in the weld overlay and may thus significantly improve its tribological properties. The particles with high Ti (TiB_2) content are present just in low concentration in weld overlay, which suggests the possibility of their dissolving during surfacing process. This is also proved by an increased Ti content in Ni matrix.

Based on the results of the presented experimental program it can be stated that the samples which were laser deposited by addition of CS 52 + 30% CrB_2-TiB_2 powder mixture directly to surfacing process showed excellent properties mainly from the viewpoint of abrasive wear resistance.

This work was supported by Slovak Research and Development Agency under the contracts No. APVT-99-P01205 (APVT012), APVT-20-020904, APVT – 20-01 1004 (APVT 403).

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