MICROSTRUCTURE AND PROPERTIES OF GRADED METAL-CARBIDE CLADDINGS

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ABSTRACT

The powder-fed laser beam cladding process is an attractive processing method to produce a graded metal-carbide multilayer structure by varying the chemical composition starting from a metal-rich composite up to a carbide-rich outer region. Detailed investigations have been carried out using NiBSi as matrix alloy and chromium carbide (Cr_3C_2) as hard and wear resistant phase. The particle shape and the distribution of the reinforced phase were determined for cladded graded structures using chromium carbide with two different particle sizes. The dependence of the microstructure and the wear resistance on the carbide content and the laser process parameters were determined.

INTRODUCTION

Surface engineering has been defined as "the application of surface technologies to engineering components in order to produce a composite material with properties unattainable in either the base or surface material".[1] For instance, the life cycle of components may be extended by application of wear resistant claddings consisting of a high content of hard carbide particles embedded in a ductile metal matrix. These metal matrix composite materials, however, have physical and mechanical properties different from the base material. Under service load, stress related failure may occur due to the mismatch at the interface between substrate and surface layer; hence the application of a graded layer that has a high carbide content at the surface in order to meet the functional requirements and a high metal content in the vicinity of the interface to match the base metal properties.[2,3] Functionally graded materials (FGM) and graded surface layers can be produced using a laser beam cladding technique that allows a locally limited heat input and a good control of the microstructure.[4,5]

EXPERIMENTAL

In laser beam cladding, a consumable powder is fed continuously into a melt pool on the surface of the substrate. The melt pool is generated and maintained through the interaction with the laser beam which forms a high intensity heat source. As the substrate is scanned relative to the beam, the material solidifies and a clad track is deposited on the surface (Figure 1).

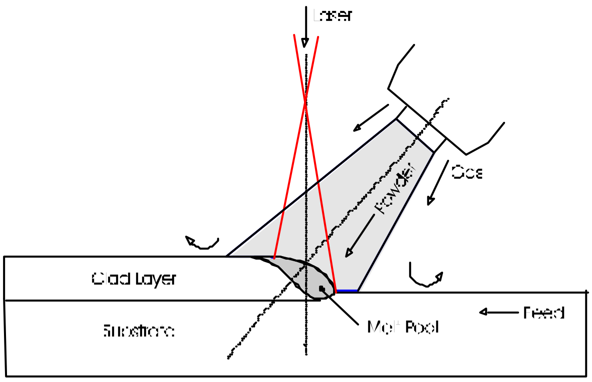


Figure 1. Principle of the laser beam cladding process

A layer is formed successively by tracks deposited side by side and multilayer structures are generated by depositing multiple layers on top of each other.

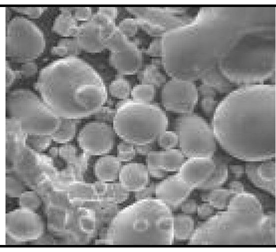
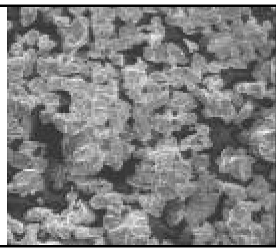
For dosing the powder mixture in the desired composition two separate pneumatic powder hoppers – one filled with the matrix alloy powder, the other filled with the carbide powder – are used. Each of these powder hoppers can be controlled separately. The two powder streams are fed together and the ratio of the metal and hard phase powder can be adjusted exactly.[4,5]

A nickel-base alloy (NiBSi) as matrix alloy and two chromium carbide powders (Cr_3C_2) with different particle sizes as hard phase are used, where in the following text the finer chromium carbide is denominated as "I" and the coarser one as "II". Table I shows the chemical composition, the grain size and their morphologies.

Starting with the nickel alloy, the amount of chromium carbide in the consumable powder mixture is increased steadily to generate multilayer structures with a compositional gradient.

A fibre-coupled 600 W cw Nd:YAG laser with 200 mm focussing optics has been used. Working in the focus with a beam diameter of 0.6 mm, the graded structures were generated. For this study, only the relative velocity of substrate and laser beam (20 – 40 mm/s) are varied. All other process parameters (laser power, the offset between two subsequent clad tracks and layers, powder feedrate) were kept constant.

Table I. Particle size, morphology and chemical composition of the used powders

Powder	**NiBSi**	**Cr_3C_2 (I)**	**Cr_3C_2 (II)**
Particle size	-105 +45 µm	-45 +05 µm	-106 +45 µm
Morphology 80 µm			
Chemical composition	Si 2,30 %; B 1,39 %; Fe 0,06 %; Ni balance	Fe 0,29 %; Cr 86,0 %; C 13,43 %	Fe 0,21 %; Cr 87,06 %; C 12,97 %

For microstructural investigations and the determination of the mechanical properties, multilayer structures with a step-wise gradient in the chemical composition were produced. The samples allow a direct correlation between composition and microstructure or material properties, respectively. The wear tests are carried out using samples with a constant composition.

The microstructural examinations were carried out on cross sections with quantitative image analysis (Image C). The size and the shape of the carbides for both material combinations, depending on the chromium carbide content (0 – 70 vol% Cr_3C_2) and on the velocity, were determined. The wear investigations are carried out using a wear tribometer. An aluminium oxide ball, which is mounted on a pin, loads the cladded samples with a specified force (F = 10.7 N). The ball is moved linearly over the surface of the sample with a fixed number of cycles. Because of the friction between ball and sample a linear track of wear arises, and the cross section area of the track was measured afterwards. In dependence on the chemical composition and the relative velocity, the rate of wear for different numbers of cycles (10,000 up to 100,000) was determined.[6]

MICROSTRUCTURE

A longitudinal section of a graded metal- carbide particle cladding is given in Figure 2. The image covers carbide contents from 30 vol% (at the bottom) to 70 vol%, and the compositional gradient is clearly evident.

Figure 3 shows the typical microstructure of a metal-carbide particle composite. In general, with an increase of the added carbide the microstructure is characterised by an increasing number and size of undissolved or partly dissolved carbide powder particles (1). The carbide particles dissolve from outside to inside, consequently the particles may lose their blocky shape, become round and their size is reduced. At a total dissolution they reprecipitate in needle-shape (2) mainly in the modification Cr_3C_2.[7]

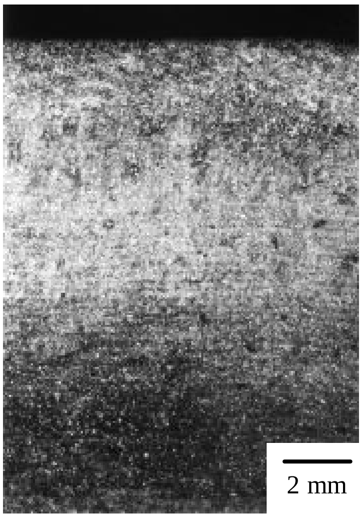


Figure 2.
Longitudinal section of a gradient material with 30 – 70 vol% Cr_3C_2 (I)

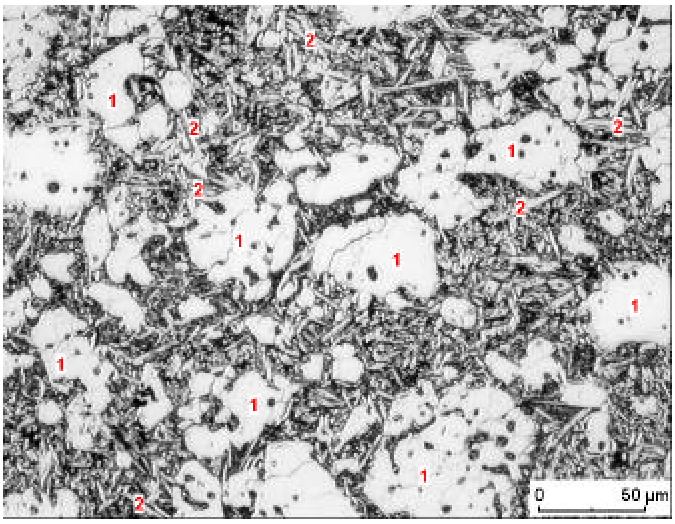
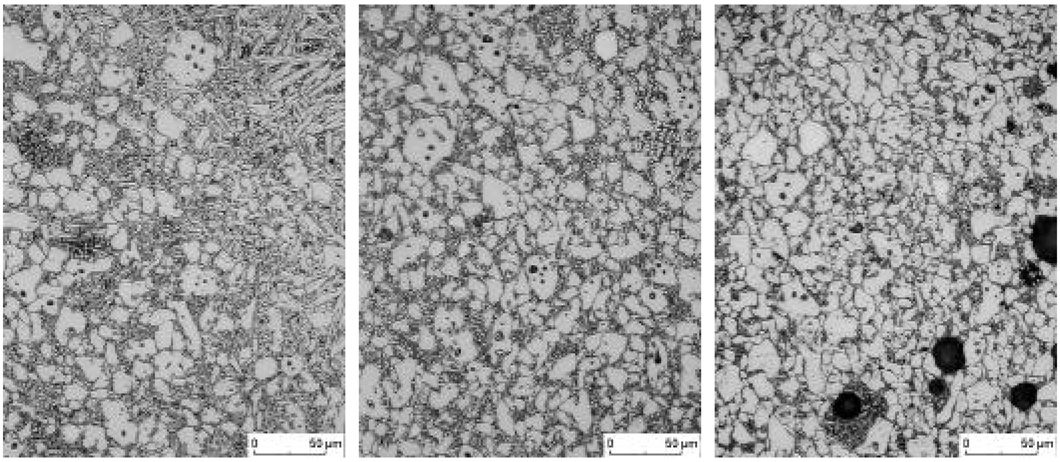


Figure 3. NiBSi + 50 vol% Cr_3C_2 (II), v_s = 20 mm/s

(1) blocky, primary chromium carbides
(2) needle-shaped, secondary chromium carbides

The kinetics of carbide dissolution and consequently the size, number and shape of the undissolved carbides depend on the process parameters, particularly on the heat input. Temperature and interaction time determine the degree of dissolution of the carbide powder particles and thus the chemical composition of the matrix as well as the precipitations of carbides from the melt.[4,8,9]

Generally, the number of undissolved carbides increases with increasing velocity, whilst the number of precipitated secondary carbides is reduced, Figure 4. The porosity, however, is particularly present at higher velocities (Figure 4c), when the heat input is low and gases are trapped in the cladding. The higher porosity may occur as a result of the decomposition of the carbides if process parameters are detrimental. The best result is obtained using a velocity of 30 mm/s. The embedded chromium carbide is mainly undissolved and homogeneously distributed. Increasing the interaction time (v_s = 20 mm/s), a high fraction of the carbide is dissolved and reprecipitated.



a) NiBSi + 50 vol% Cr_3C_2 (I) v_s = 20 mm/s

b) NiBSi + 50 vol% Cr_3C_2 (I) v_s = 30 mm/s

c) NiBSi + 50 vol% Cr_3C_2 (I) v_s = 40 mm/s

Figure 4. Effect of the relative deposition velocity on the microstructure of NiBSi + 50 vol% Cr_3C_2 (I)

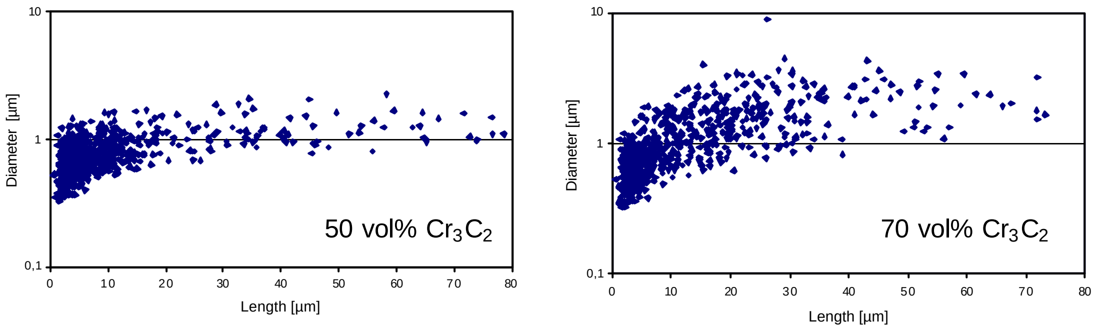
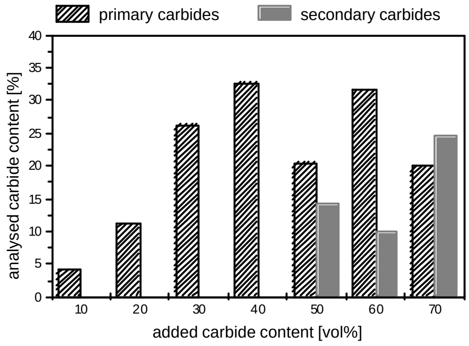


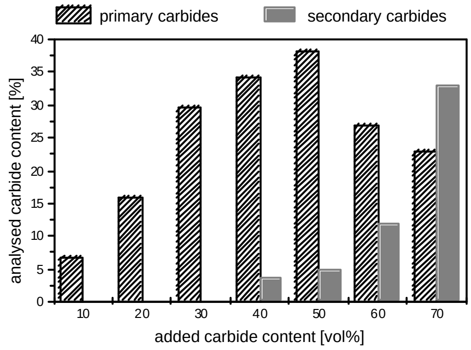
Figure 5. Diameter and length of the precipitations depending on the carbide content for NiBSi + Cr_3C_2 (I), v_s = 20 mm/s

Quantitative micorstructural analysis was carried out to explain and quantify the influence of process parameters and chemical composition on the microstructure and wear properties. As the dissolution behaviour of the added carbide particles is of special interest, their number, shape and area fraction was determined. The dissolution process or behaviour is independent on the powder combination. With increasing interaction time (i.e. decreasing velocity) and increasing carbide content the number of secondary precipitations increases and they become longer and thicker (Figure 5).

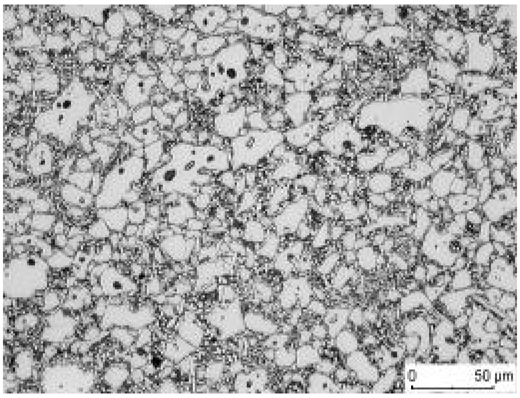
Indeed, the dissolution starts earlier using the coarser chromium carbide powder in contrast to the carbide I (Figure 6). At a velocity of 20 mm/s the first needle-shaped precipitations occur at 40 vol% of the chromium carbide II (Figure 6b), whereas undissolved carbides of the finer particle powder occur using the same process parameters (Figure 6a). The diagrams illustrate that the added carbide content, which is fed into the melt pool, is in good agreement with the total carbide content detected by the analysis software. By X-ray diffraction phase analysis mainly, Cr_3C_2 type carbides and only small quantities of the chromium rich Cr_7C_3 type carbides have been found.[6]



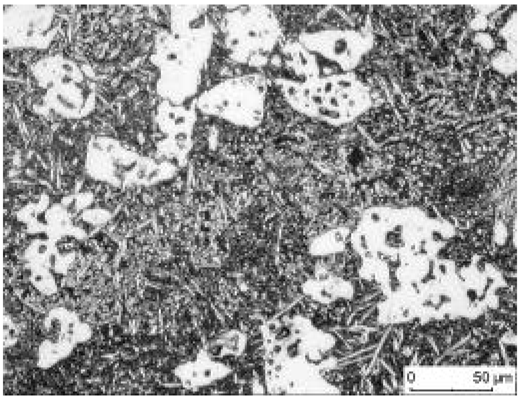
a) NiBSi + Cr_3C_2 (I), v_s = 20 mm/s



b) NiBSi + Cr_3C_2 (II), v_s = 20 mm/s



c) NBSi + 40 vol% Cr_3C_2 (I), v_s = 20 mm/s



d) NiBSi + 40 vol% Cr_3C_2 (II), v_s = 20 mm/s

Figure 6. Microstructure of NiBSi + Cr_3C_2 depending on the chromium carbide size

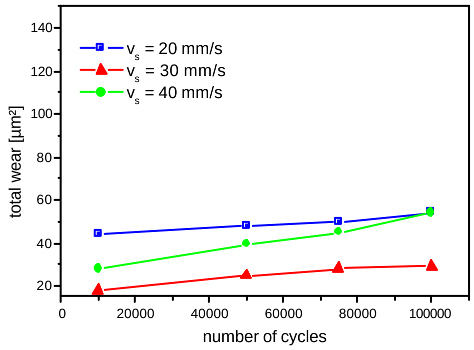
WEAR PROPERTIES

Independent of the particle size of the chromium carbide, the total wear [µm²] increases with increased number of cycles (Figure 7a + Figure 7b) and decreasing carbide content (Figure 7c + 7d). Varying the relative velocity the best wear result is obtained at v_s = 30 mm/s (Figure 7a + Figure 7b). Remarkable is the jump of the total wear at 100,000 cycles using the coarser chromium carbide (Figure 7b).

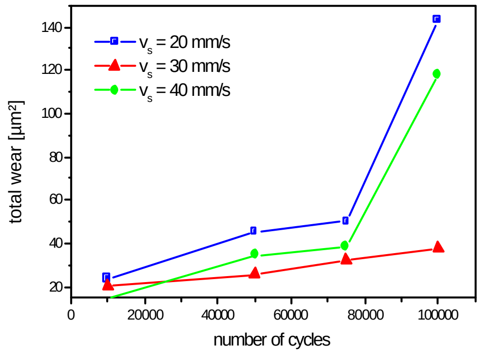
The results of the wear tests can be correlated with the microstructure. Both the wear resistance and the microstructure show the best results at a velocity of 30 mm/s. The microstructure is nearly defect-free and most of the added chromium carbide is embedded undissolved in the metal matrix (Figure 4). The good quality of the metal-carbide composite is responsible for the low rate of wear. At v_s = 20 mm/s the hard phases dissolve; at a higher velocity (v_s = 40 mm/s) defects occurred like bonding problems, cracks or pores.

At a number of cycles lower than 75,000 the wear resistance using the coarser carbide (II) is more favourable comparable to the finer one (I). At higher number of cycles it is vice versa. Figure 8 shows the failure behaviour of the metal-hard phase composite. Generally the hard phases break into pieces under the load. The interface strength between metal matrix and hard particles is excellent, no detachment of whole particles is observed. Beyond that, only primary carbides fail, needle-shaped precipitated chromium carbides show no failure. Using a finer chromium carbide

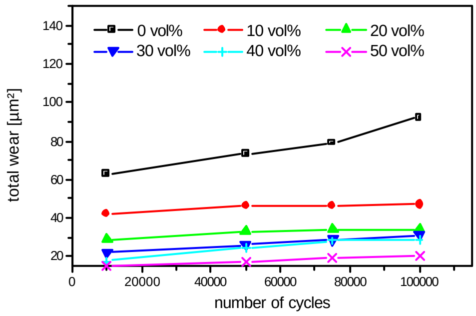
(I), the hard particles are very small and homogeneously distributed, the load is distributed on a higher number of particles. The failure of the coarser Cr_3C_2 particles significantly weakens the microstructure and the wear resistance falls rapidly off. Only the primary chromium carbides break into pieces, the needle-shaped precipitations don't fail during the wear testing and are well embedded in the metal matrix.



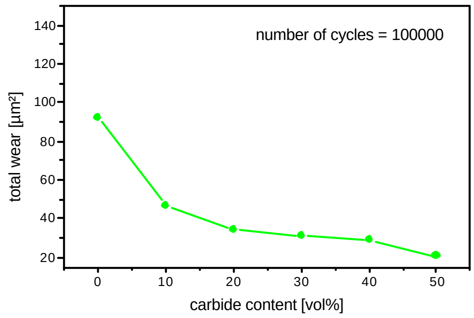
a) NiBSi + 40 vol% Cr_3C_2 (I)



b) NiBSi + 40 vol% Cr_3C_2 (II)

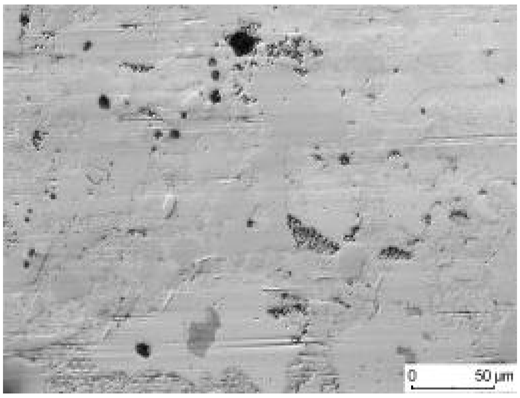


c) NiBSi + Cr_3C_2 (I), v_s = 30 mm/s

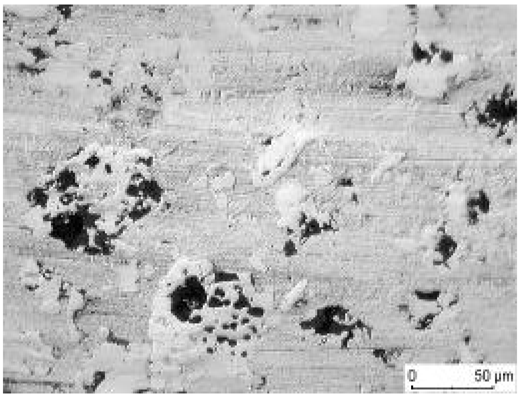


d) NiBSi + Cr_3C_2 (I), v_s = 30 mm/s

Figure 7. Dependence of the total wear on the number of cycles and the carbide content



a) NiBSi + 40 vol% Cr_3C_2 (I), v_s = 30 mm/s



b) NiBSi + 40 vol% Cr_3C_2 (II), v_s = 30 mm/s

Figure 8. Images from NiBSi + Cr_3C_2 after the wear testing (number of cycles 100,000)

CONCLUSIONS

Multilayer coatings with a gradient in the chemical composition can be produced using the powder-fed laser beam process. The concentration gradient allows the generation of metal-carbide composites with a high content of hard particles.

Independent of the particle size ratio between the metal and the carbide powder, crack-free samples can be produced at similar process parameters. The dissolution behaviour of the added hard phases happens in the same manner.

With decreasing relative velocity and/or increasing carbide content the added chromium carbides (Cr_3C_2) dissolve and precipitate mainly in the same modification. Using a coarser chromium carbide the dissolution process starts earlier in comparison to a finer one.

The wear test results are excellent, if cladded multilayer structures are defect-free and the hard particles are well embedded in the metal matrix. Increasing the carbide content the capacity of resistance to wear increases. Using the coarser chromium carbide (II) a failure is observed at higher number of cycles. The embedded hard particles break into pieces and quarry out, whereas the bonding strength between metal matrix and hard phases remains strong.

ACKNOWLEDGEMENTS

The authors would like thank the German Research Association (DFG) for their beneficial support of the research described in this paper.

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