Overlay welding of NiSiB mixes with tungsten carbides

B. Maroli[1], C. Liu[2]
[1]Höganäs AB, Höganäs, 26332, Sweden
[2]Höganäs China, Shanghai, 201700, China
*Corresponding author: barbara.maroli@hoganas.com

Abstract— Metal-matrix composite coatings consisting of a nickel based metal matrix and tungsten carbides are commonly used for hardfacing of components requiring resistance to abrasive wear. The nickel based matrix works as a binder providing toughness while the tungsten carbides provide wear resistance. The properties of metal matrix composite coatings depend on the volume fraction of carbides in the clad but also on the shape, particle size and microstructure of the carbide particles, the chemistry of the matrix material and the process parameters selected. In this paper, the properties of laser cladded and PTA welded nickel based coatings with different amounts of tungsten carbides are investigated.

Keywords - hardfacing; laser; NiSiB; PTA; cladding; welding

I. INTRODUCTION

Abrasive wear is the major failure mode for industrial components. Coating of the exposed surface with a more wear resistant material is both a cost efficient and sustainable route to increase the life length of industrial parts. Overlay welding by laser or plasma transferred arc of powder mixes consisting of a nickel based self-fluxing alloy and tungsten carbides is an effective way to protect the surface of a component against abrasive wear.

Laser cladding and PTA welding ensure a strong metallurgical bonding to the substrate combined with limited dilution from the parent metal, typically below 15%. The low heat input and fast cladding speed of the laser cladding process result in a lower dilution from the substrate, when compared to PTA and limited distortion of the coated parts. The faster solidification rate however, increases the risk for crack and pore formation in the final clad. PTA welding allows depositing weld beads having larger width and height when compared to laser cladding. Several types of PTA and laser cladding equipment are available on the market and selection of the most suitable equipment and deposition method depends on the application requirement.

In metal matrix composite coatings containing tungsten carbides the nickel matrix works as a binder providing toughness while the tungsten carbide particles provide wear resistance.

Applications of tungsten carbide metal matrix composite coatings are found in the mining industry to coat different drilling and digging parts, in agriculture for coating of plough shares, tillage equipment and cutters. In the steel industry, tungsten carbide coatings are deposited on guide rollers while the oil & gas industry uses these coatings on rock bits and drilling stabilisers.

The aim of this work is to investigate the abrasive wear resistance and microstructure of laser cladded and PTA welded NiSiB coatings with different amount of tungsten carbides.

Fig. 1. Excavator bucket teethes are one of the applications where nickel based coatings with tungsten carbides are applied to protect against abrasive wear.

II. EXPERIMENTAL

Four mixes, based on a nickel based matrix and two different amounts of eutectic tungsten carbides, 50 respectively 60wt% were used for the experiments. The chemical composition of the investigated mixes is summarized in table1. Höganäs grade 1559-40 pre-alloyed with nickel, silicon and boron (Ni bal., 2.9wt% B, 3wt% Si) was used as a matrix material. Spherical cast tungsten carbides (SCC), Höganäs grade 4590, were used for laser cladding while fused and crushed tungsten carbides (FTC), Höganäs grade 4570, were used for PTA welding. Both the SCC and FTC carbides have a eutectic structure consisting of a mixture of WC and W_2C carbides. For laser cladding, spherical cast carbides were selected, as they are the common choice in the industry. Fused and crushed tungsten carbides were instead used for PTA welding as they are frequently used in combination with this coating method. Particle size of the carbides measured by laser diffraction showed d_{50}=80µm for the SCC carbides and d_{50}=95µm for the FTC carbides.

Table 1. Mixes used for PTA and laser cladding trials

Mix	*Deposition method*
A. 1559-40+50wt% SCC	Laser Cladding
B. 1559-40+60wt% SCC	Laser Cladding
C. 1559-40+50wt% SCC	PTA
D. 1559-40+60wt% SCC	PTA

Laser cladded was performed using a 4kW direct diode laser with 12x1 mm spot size. EN S235JR mild steel coupons with size 210x60x20mm were used as substrate material. The substrate were pre-heated at 400°C in air to reduce the risk for crack formation. Cladding was carried out using a power of 2 kW, 3 mm/sec cladding speed and a powder feed rate of approx. 30 g/min. PTA welding was carried out using a Hettiger 200A PTA unit. The substrates were EN S235JR plates with size125x40x20 mm, pre-heated at 350°C. Both the PTA and laser cladded samples were cooled in vermiculite. The cladding parameters were selected in order to assure good bonding to the substrate, good mixing of the coating material with the parent metal (substrate material) and minimal dissolution of the tungsten carbides.

The samples were evaluated for abrasive wear and microstructure. Abrasive wear testing was performed according to ASTM G65, procedure A [1], by using a commercial sand/wheel abrasion tribometer. Five sample replicas per tests material were investigated. The cross section of the clads was investigated by light optical microscope (LOM) and scanning electron microscope equipped with backscatter detector (SEM-BSE). The clads were sectioned transversal to the cladding direction, moulded in bakelite, ground and polished. Final polishing was carried out using colloidal SiO_2. The chemistry of the coating was analysed on the surface exposed to the wear test using a hand held XRF gun with 3 mm spot. The chemistry was analysed to estimate the degree of dilution from the substrate material. Dilution was calculated as:

$$Dilution = \frac{C_{Powder} - C_{Cladding}}{C_{Powder} - C_{Substrate}}$$

where, C_{Powder} is the composition of the powder used, $C_{Substrate}$ is the composition of the substrate and $C_{Cladding}$ is the measured composition of the clad. To improve the accuracy of the result iron was selected as this element has low concentration in the coating and high concentration in the substrate.

III. Results

The dilution from the substrate in the laser cladded samples was 10% while that of the PTA welded samples was 15%.

Results from the abrasive wear test are presented in figure 2. Average volume loss (mm^3), AVL, decreased moderately when raising the amount of tungsten carbides from 50 to 60 wt% both for the PTA and laser cladded samples. However, no major differences in AVL were observed between the laser cladded and PTA welded samples with similar amount of tungsten carbides.

Figure 2. AVL (mm^3) of laser cladded and PTA welded mixes based on 1559-40 with 50 respectively 60wt% tungsten carbides

Microstructure of the laser cladded and PTA welded samples containing 50wt% tungsten carbides is shown in figure 3. During overlay welding partial dissolution of the eutectic WC/W_2C tungsten carbides took place and a layer of blocky shaped tungsten rich carbides formed at the interface with the matrix and in the matrix it-self. As illustrated in figure 3 and 4 the PTA welded clads showed a larger degree of dissolution of the tungsten carbides than the laser cladded one. Further, both the blocky shaped carbides, formed at the periphery of the original tungsten carbide particles and those precipitated in the nickel-based matrix were somewhat coarser in the PTA welded samples.

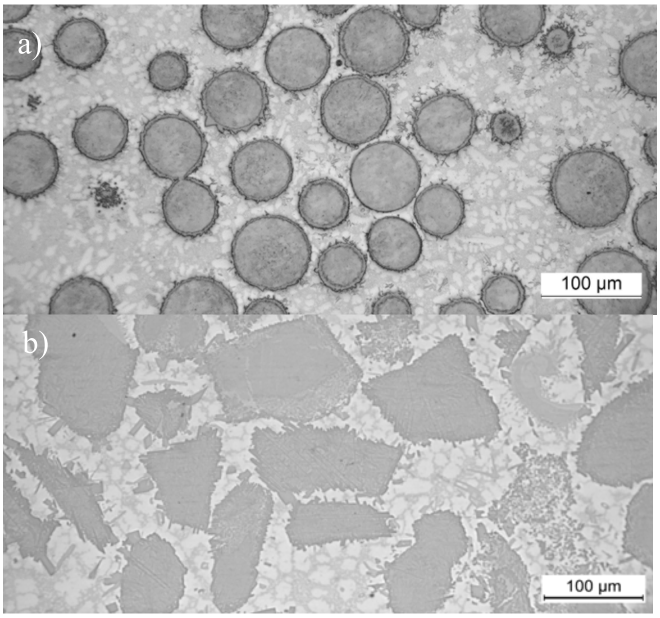

Figure 3. Microstructure of a)1559-40+50wt% 4590, laser cladded; b) 1559-40+50wt% 4570 welded as observed under a LOM.

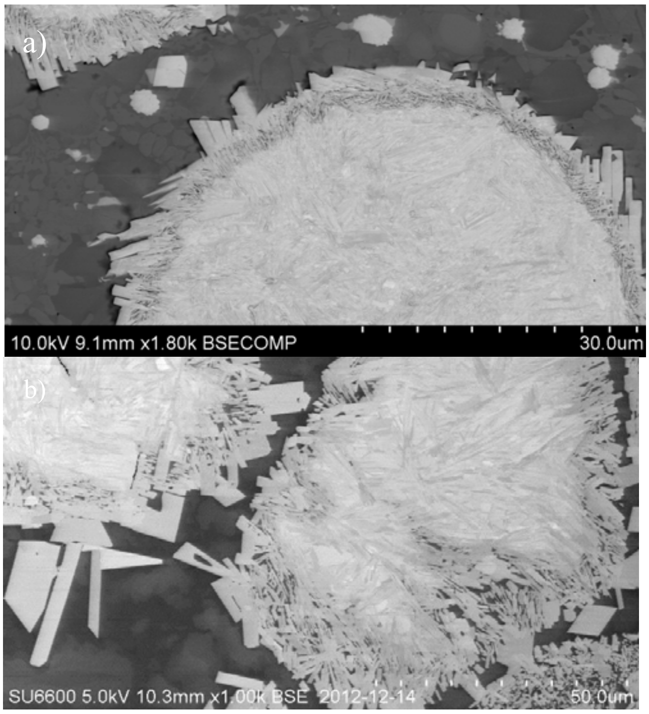

Figure 4. SEM-BSE photos showing different degree of dissolution of the tungsten carbides; a)1559-40+50wt% 4590, laser cladded; b) 1559-40+50wt% 4570, PTA welded

In the laser cladded samples the distribution of the carbides in the clad was rather even while sinking of the tungsten carbides to the bottom of clad was observed in the PTA welded samples as illustrated in figure 5.

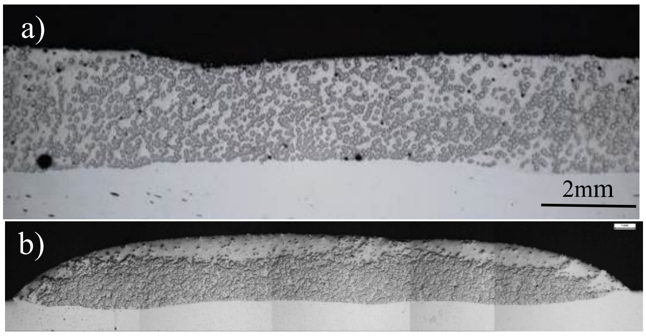

Figure 5. The micrographs show the distribution of the tungsten carbides in a)1559-40+50wt% 4590, laser cladded; b) 1559-40+50wt% 4570 welded as observed under a LOM.

IV. DISCUSSION

The energy provided by the PTA and laser cladding processes aim at melting the NiSiB matrix keeping the tungsten carbide particles in the solid state. However, during welding carbon and tungsten atoms diffuse from the carbide particles into the liquid matrix and vice versa Ni and Fe atoms diffuse from the liquid matrix into the carbide particles. Carbon atoms diffuse substantially faster than the substitutional alloying elements W, Ni, Fe etc. due to their smaller size. This results in the formation of a layer of blocky shaped tungsten rich carbides, either W_2C or η-carbide $(W,Ni,Fe)_3C$ [3, 4] at the interface between the tungsten carbide particles and the nickel based matrix. These carbides are softer than the primary WC/W_2C eutectic carbides, therefore extensive dissolution of the original eutectic carbides is detrimental for the abrasive wear resistance of a clad. The higher the heat input and the lower the solidification rate, the larger the dissolution degree of the tungsten carbide particles.

The dissolution of the original tungsten carbide particles also enriches the liquid matrix with W and C causing the precipitation of tungsten rich carbides in the matrix during solidification. This increases the matrix hardness, reduces its toughness and the impact wear resistance of the clad. Large abrading particles and a ductile matrix are beneficial for abrasive and impact wear resistance of nickel based clads with tungsten carbides.

There are other factors influencing the degree of dissolution of the tungsten carbides as for example the chemical composition of the matrix, the microstructure, amount, size and shape of the carbide particles.

The distribution of the tungsten carbides is another factor affecting the final properties of a clad. The high density of the tungsten carbides combined with the low melting point and large solidification interval of nickel based self-fluxing alloys allow time for the tungsten carbide particles to sink to the bottom of the melt pool. The lower the heat input, the higher the solidification rate the less the risk for sinking of the tungsten carbide particles. The amount of solid carbide particles in the melt pool also affects their final distribution in the clad. The larger the amount of carbides, the lower their mobility in the melt pool and therefore their possibility to sink. The tendency to sink of the tungsten carbide particles may result in an uneven carbide distribution and therefore uneven properties in the final clad.

The PTA welded samples prepared in this investigation showed a more uneven carbide distribution when compared to the laser cladded one. This due to the lower solidification rate of the PTA welded samples, which gave more time to the carbide to settle to the bottom of the melt pool. Sinking of the tungsten carbides to the bottom of the melt pool is not critical in a number of industrial applications, as the surface layer with lower concentration of tungsten carbides is removed during function.

For measurement of abrasive wear, the surface of the investigated samples was grinded to fulfil the requirements of ASTM G65. Therefore, the layer with low carbide content at the surface of the PTA welded samples, shown in Fig. 5, was removed and abrasive wear was measured on a surface having a somewhat higher concentration of carbides than the nominal one due to sinking of the tungsten carbide particles to the bottom of the melt pool.

In the case of the investigated samples, AVL was similar for the laser cladded and PTA welded samples with similar amounts of tungsten carbides despite the somewhat larger degree of dissolution of the tungsten carbides in the PTA welded samples. This could be due to the slightly higher volume fraction of tungsten carbides on the tested surface, when compared to the laser cladded one.

The selection of the metal matrix, type and amount of tungsten carbides depends on the application requirements and deposition method available. Optimising of the process parameters for each mix, type of component and deposition process is necessary to achieve sound clads with limited dissolution and even distribution of the tungsten carbides.

V. Conclusions

The properties of laser cladded and PTA welded commercial nickel based mixes with 50 respectively 60 wt% eutectic tungsten carbides are investigated.

- Slight increase in AVL is observed when raising the amount of tungsten carbides from 50 to 60 wt% for both the laser cladded and PTA welded samples.
- PTA welding and laser cladding result in similar abrasive wear resistance for the same amount of tungsten carbides.
- Low heat input and fast solidification rate minimise the dissolution of the tungsten carbides in the melt pool.
- Low heat input and fast solidification reduce the risk for sinking of the tungsten carbides to the bottom of the melt pool and result in a more even distribution of the tungsten carbides in the final clad.

Acknowledgment

The authors would like to thank Mr Mattias Weibull and Peter Olsérius for the patience and accuracy in performing the laser cladding respectively PTA welding trials and Dr Senad Dizdar for valuable discussion in the preparation of this work.

References

[1] ASTM G65 - Standard Test Method for Measuring Abrasion Using the Dry Sand/Rubber Wheel Apparatus.
[2] B. Maroli, S. Dizdar *ITSC2015: 2015 Int. Therm.Spray Conf. & Exhib.*, 11-14 May, 2015, Long Beach, USA.
[3] C. Katsich *et al. Surface & Coating Technology*, Vol. 206 (2011), pp 1062-1068.
[4] M. Jones *et al*, *Wear*, Vol 271 (2011), pp. 1314-1324