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Wear behaviour of laser clad WC-Co powder

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Abstract

This paper shows laser cladding using WC-Co on low carbon steel and the microstructural characteristics of the resulting coating. It also analyses wear behaviour for different load and velocity conditions through a P-V diagram .

1 Introduction

The increasing demands on mechanical elements for higher pressure, temperature and load resistance usually involve increasing the demands on the materials used to manufacture them too. New technologies are, therefore, being developed to minimise the effects of friction, wear, corrosion, radiation, etc. on such elements.

One of the methods used to improve the materials surface is thermal spraying. It consists of spraying a coating, made of different materials, onto a base material. The thickness of the coating may range from a few microns to several millimetres, depending on the characteristics of the base material, the spraying method and the purpose for which it is used.

This paper describes a method to obtain tungsten carbide coatings, of high industrial interest [1], sprayed on low carbon steel, using CO_2 laser technology; a technique still new in this field [2]. It also incorporates a description of the most outstanding characteristics of the resulting layers (adherence, porosity, hardness, micrographic structure, etc.), with special attention to wear behaviour illustrated by means of the P-V diagrams from the tribological tests.

1.1 Laser surface cladding

Laser can be a useful tool for the coating process, particularly when the base material is metallic, since both, the surface of the base material and the filler

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metal melt together forming the final layer.

The purpose of laser surface cladding is to melt with laser a material, which is commonly sprayed in powder form on the base material using inert gas. The dilution among the coating and the substrate must be reduced to a minimum value. In this manner, the resulting layer is little affected by the base material, preserving the resistance of the materials that form it [3].

Each area is laser clad only once, overlapping the tracks, as shown in figure 1.

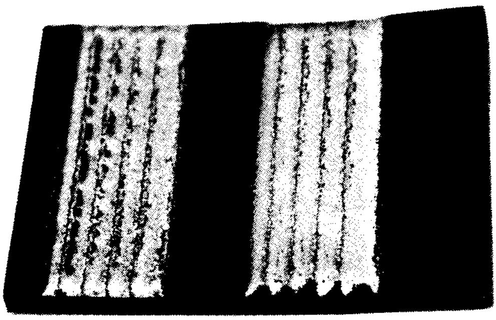

Figure 1. Development of a uniform layer where the tracks are overlapped, fort different speeds.

1.2 Measuring and predicting wear.

A clear and precise definition of wear is not possible because in most cases several types of wear occur simultaneously [4].

However, the PV factor specifies wear for contacts with limit lubrication conditions. Such factor results from multiplying contact pressure by sliding speed and can be experimentally obtained for every two-body contact [5]. It is based on the fact that wear D (amount of detached material) is directly proportional to the energy lost during sliding.

$$D \propto \mu F.V$$

Where μ is the friction rate ($\mu \approx$ constant), F is the normal load at the contact and V the sliding speed. This can also be expressed using linear units

$$\frac{D}{A} \propto \frac{F}{A} \cdot V = P \cdot V$$

Where A is the apparent contact area.

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Results can be presented in what is known as P-V diagrams. These provide a good mean to check quickly whether a certain friction pair is suitable for given speed and load conditions , as it is the case with bearings and ball joints. However, lack of sufficient experimental results makes their use still limited.

2 Experimental procedure

Surface cladding was carried out using a Rofin Sinar fast axial flow CO_2 laser with 10.6 μm wavelength, operating in beam mode TEM 01*, and 1700 W nominal power.

After several initial tests, experimental conditions were fixed using power densities ranging from 3400 to 5000 W/cm^2. For the base material, AISI 1043, a low carbon steel, was selected.

The material chosen for the coating was a mixture of cobalt-tungsten carbide powders and self-fluxing nickel-chromium alloy powders (its melting point is 1025 °C), with average particle sizes of: -270 mesh + 15 microns. The powder composition is : 50%-(WC-12%Co); 33%-Ni; 9%-Cr; 3.5%-Fe; 2%-Si; 2%-B; 0.5%-C [6].

The powder was injected using a Metco 4MP as powder feeder and argon with 3 bar pressure as carrier gas. Flows of 9 and 7 g/min were used; the movement of the beam over the piece was monitored from a numerical control two-axis table using speeds from 200 to 1200 mm/min.

Finally, microstructural analyses were carried out by means of optical microscopy and with a SEM. Hardness, microhardness, cracking and porosity were also studied.

Adherence between coating and base material was tested according to ASTM C633-69, NF A-91-200 and PT-MC-140. The traction tests were performed with a 250 KN MTS machine, at 1mm/min speed

As required in ASTM G77, the wear tests were carried out with two different types of test specimens, block and ring. After cladding, the 15.75x10.16x6.35 mm.blocks (stationary test specimen) made of AISI 1043 steel (fig.3), are ground and put in contact with a 60 mm-diametre rings (mobile test specimen) made with the same type of steel, with block-on-ring contact, allowing a continuous speed variation between 0 and 3000 rpm. Tests were performed under lubrication conditions with SAE20 oil of 8,3 cSt viscosity at 100°C and 61,4 cSt at 40°C.

The process to carry out the tests consisted in fixing the rotation speed of the ring (and hence the sliding speed) and increasing the normal load every 20 seconds [7]. At the same time, friction force at the interface was recorded using

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a Philips PM8272XYt recorder.

Whenever friction increased sharply (severe wear zone) the tests were stopped, as shown in figure 2. The result of dividing the normal load at that stage by the area of the worn-out surface of the block, measured using optical systems once the test was over, is the maximum pressure the contact can withstand for the test conditions.

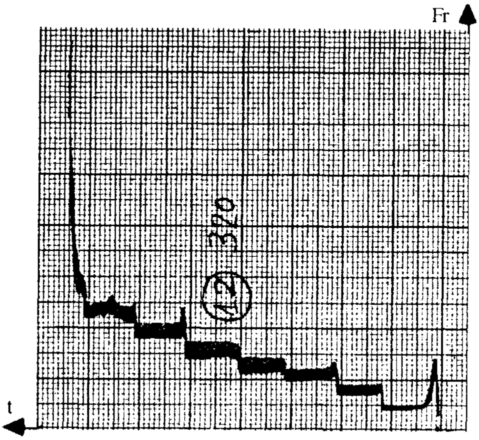

Figure 2. Recorded friction coefficient for V=1 m/s.

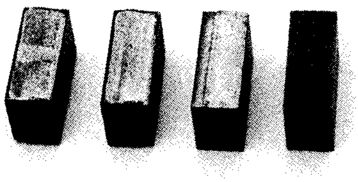

Figure 3. From right to left: unclad, clad, ground and wear tested block.

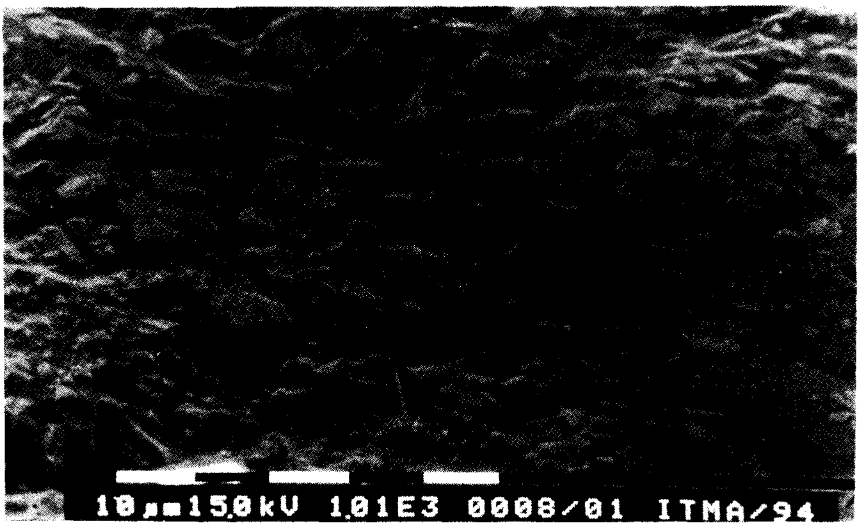

Figure 4. External appearance of the layer (x1000).

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3 Results and discussion

Figure 4 shows the external appearance of the layers after the laser treatment, and how the tungsten carbides were inserted into a matrix phase. The average thickness of the layers on the block is 0.4-0.5 mm, obtained by overlapping 50% of two 4mm wide tracks (figure 3)

The layers do not present adherence problems: in every traction test the fractures occurred at the adhesive whereas the layers withstood traction pressures above 45-50 Mpa.

There is very little porosity and only some external cracks occurred on coatings formed by several tracks (never by one single track) when the base materials is thin, probably due to the different thermal expansion coefficient of layer and substrate and to high cooling speeds..

In figure 5, the micrography evidences that the structure of the clad layer consists in a white disperse phase, which the x-ray scanner identified as tungsten carbides quite homogeneously and regularly distributed (see figure 4), although showing sometimes a trend to group, and a matrix phase divided, in turn, into a darker gray phase, with high contents in Ni, Cr, Co and Fe, and a lighter gray phase in which Cr and Ni are the main components.

LAYER SUBSTRATE

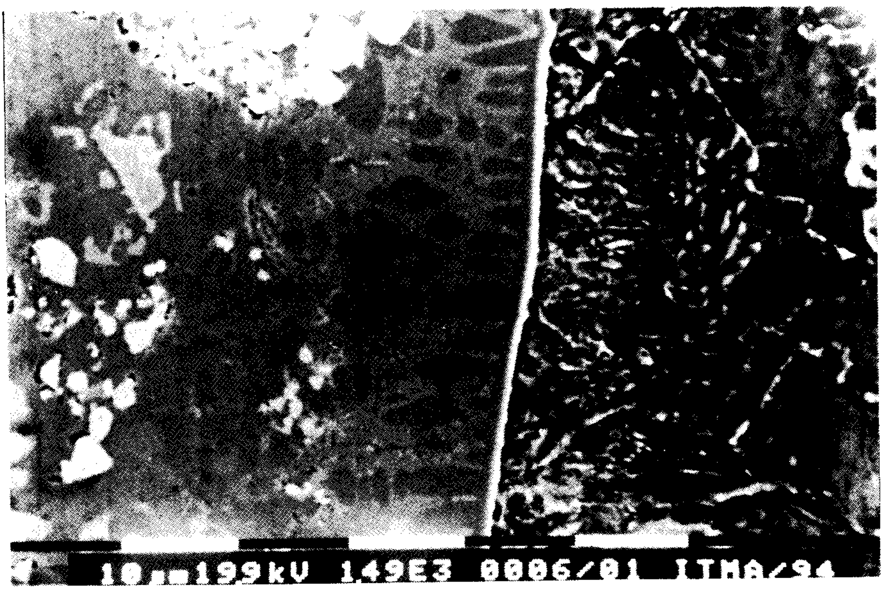

Figure 5. Detail of clad layer-substrate interface processed at 1750 W, 10 g./min. and 550 mm/min (x1500).

Next to the interface, there is a dendritic phase (figure 5). For tracks where base material dilution is low, this phase is almost non-existant, whereas in tracks with high dilution levels the percentage of dendritic structure increases remarkably. This is also evidenced by figure 6, where the microhardness graph shows that: the higher the degree of dilution, the softer the clad layer and the more gradual the hardness transition between clad layer and base material.

Around 20 microns of substrate are strongly affected by the treatment, although the heat affected zone (HAZ) is up to 1 mm thick. The HAZ increases gradually as new tracks form, due to the energy accumulated each time the laser beam sweeps the base material.

Hardness tests results for layer and base material are as follows:

Layer average hardness	64 HRC
Base material average hardness	39 HRC

Microhardness tests also provide information on the phase forming the clad layer.

Carbides hardness	1500-1800 HV_{200}
Matrix phase hardness	600-750 HV_{200}
Dendritic phase hardness	500-650 HV_{200}

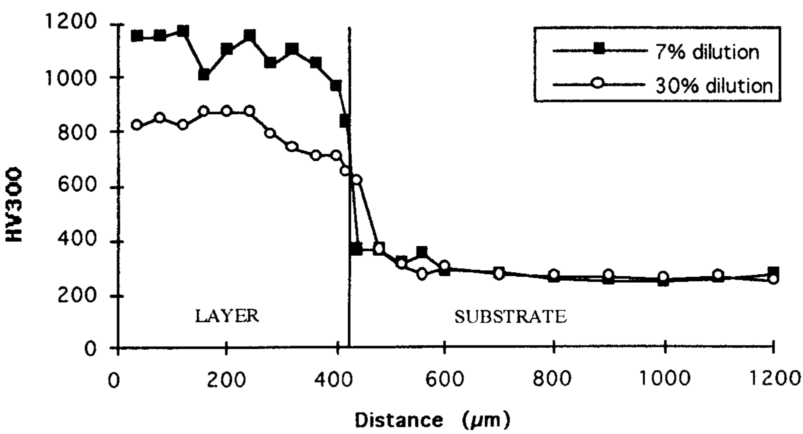

Figure 6. Hardness of 50%(WC-Co)-50%NiCrFe tracks with different degrees of dilution.

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A P-V diagram was obtained using the above described experimental procedure. By relating the maximum normal loads applied to the apparent contact area (measured by means of a profile projector) a P-V diagram was obtained for the friction pair: 50% (WC-Co)-50%NiCrFe layer coated using laser and F1140 steel, under the above-mentioned limit lubrication conditions, as shows in figure 7.

The diagram shows the high pressures withstood by these layers, under the conditions described, without particle detachment. It also shows a large zone of dots with almost linear behaviour, except for the heavier loads, corresponding to the melting point of the material, and for the higher sliding speeds which cause high temperatures, as evidenced by the P-V factor theory. [8].

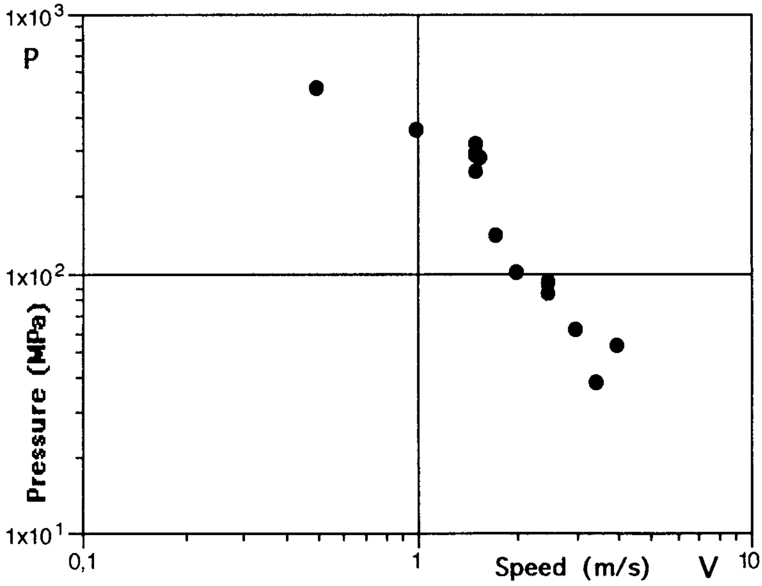

Figure 7. P-V diagram for the friction pair: 50%(WC-Co)-50%NiCrFe clad layer and F1140 steel.

4 Conclusions

As stated in previous research papers, the layers obtained using this process present the advantages of laser surface cladding over methods such as plasma spraying or arc welding [9]. Such advantages include lower dilution levels (values of 2% are possible), lower porosity, the heat affected zone (HAZ) is minimum, there is good coating-substrate adherence, fast deposition speed and the possibility of obtaining thin layers (up to 0.3 mm) or layers of up to 3 mm with one single laser sweep.

Dilution causes dendritic structures in the coating, reducing hardness. These layers can withstand high pressures for extreme working conditions and their behaviour is almost linear, as evidenced on the P-V diagram .

Acknowledgement

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