Applied Surface Science 257 (2011) 5132–5137

Contents lists available at ScienceDirect

Applied Surface Science

journal homepage: www.elsevier.com/locate/apsusc

Microstructures and mechanical properties of metallic NiCrBSi and composite NiCrBSi–WC layers manufactured via hybrid plasma/laser process

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ARTICLE INFO

Article history:
Available online 18 November 2010

Keywords:
Plasma/laser hybrid process
Composite coatings
Microstructures
Nanoindentation
Wear

ABSTRACT

Thermal spraying is already used in industry to protect mechanical parts against wear and/or corrosion, but results are not always satisfactory due to porosity and microstructures. In this study, atmospheric plasma spraying (APS) and *in situ* laser irradiation by diode laser processes were combined to modify structural characteristics of metallic NiCrBSi and composite NiCrBSi–WC coatings. The microstructure evolution was studied with the chemical composition analysis by XRD and SEM coupled with EDS techniques. Instrumented nanoindentation tests were also conducted employing a Berkovich indenter. Moreover, the effect of the influence of the volume fraction of the reinforcing WC particles on the formation and mechanical performances of the layer was also investigated. Results show that *in situ* laser remelting induces the growth of a dendritic structure which strongly decreases the porosity of as-sprayed coatings, without solidification cracking (one of the major defects that can occur during the solidification of metallic or composite alloys) and improves the mechanical properties of the layer. Indeed, the layer properties such as hardness, elastic modulus, shear strength and wear rate are dependent on the percentage of WC particles in the mixture.

1. Introduction

NiCrBSi deposits are commonly used for wear and corrosion resistance applications at elevated temperatures. However, their mechanical properties can be greatly increased by adding refractory carbides, such as WC [1]. Indeed, cermets are well-known as highly wear resistant materials used in mechanical parts for various applications [2]. Among all technologies employed to produce cermet coatings, thermal spraying gives excellent results by heating, melting the spray material and accelerating it in a high-temperature flame. Whereas, these coatings are porous and mechanically bonded to the substrate. These characteristics are not always satisfactory for industrial applications because of weak wear and corrosion resistance. In order to improve them and to increase their bonding to the substrate, a surface remelting treatment can be used to build denser coatings, without porosity, metallurgically bonded to the substrate, such as brazing type.

A technology combining atmospheric plasma spraying (APS) and simultaneous remelting is described in this paper. In order to modify the structure without generating a too high level of stress, *in situ* laser remelting appeared as an interesting alternative. Indeed, this coupled treatment permits to reach a high temperature at the surface of the sample via the spray gun, decreasing the thermal gradient. Thus a reduced level of laser energy can be used to build the coating with a lower thermal stress level than laser cladding or laser post treatment. APS coatings are carried out with advantageously high spray velocity in the range of 60–80 m/min. It seems interesting both to preserve the treatment velocity, and to improve by laser the microstructure of the coating. The greatest difficulty is to find an agreement between the very high APS process velocity and the slower laser treatment.

Self-fluxing NiCrBSi alloys have been already coated successfully via hybrid plasma/laser process as coating materials providing wear protection [3]. To enhance wear resistance it seems interesting to use this hybrid spray process giving denser coatings than APS with finer structures, without cracks and porosity, to produce other materials such as NiCrBSi–WC.

The aim of this paper is to study the behaviour of WC particles in coating and the influence of the laser treatment on the layer structures, related to the degree of WC in the metallic NiCrBSi matrix. The mechanical properties of NiCrBSi–WC composite coatings obtained by *in situ* remelting are also studied.

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doi:10.1016/j.apsusc.2010.11.062

Table 1
Chemical composition (wt.%), morphology and particle size distribution of spray powders used for laser hybrid treatment.

Powders	Chemical composition (wt.%)							
	W	C	Ni	Fe	Cr	Si	B	O
NiCrBSi	–	0.78	Balance	3.27	14.80	4.41	3.17	0.046
WC	Balance	4	–	–	–	–	–	–

	Morphology	Particle size distribution
NiCrBSi	Spherical	Ranging from 20 to 63 μm (average 45 μm)
WC	Crushed	Ranging from 20 to 63 μm (average 45 μm)

2. Materials and methods

2.1. Coating manufacturing and processing parameters

2.1.1. Feedstock materials

NiCrBSi and WC powders have been chosen as feedstock materials to carry out the coatings. Powders from Höganäs, referenced as grade 1160-00 for NiCrBSi and 4670 for WC were used (Table 1). Powders are combined in order to obtain a mix in the range of 5–50 wt.% of WC in NiCrBSi. These powders were sprayed on a C38 steel pin with a diameter of 25 mm.

2.1.2. Coating operations

The experimental device of the hybrid plasma spray process was constituted by the coupling of a plasma spray gun and a diode laser (3 kW, average power) of 848 nm wavelength (Fig. 1 and Table 2). Before spraying operations, samples were degreased and grit blasted using Al_2O_3 powder (grain size: 250 μm) to remove surface oxides and create a minimum surface finish of approximately Ra = 5 μm. Then the samples are placed on a linear moved holder and they are swept by the plasma gun and *in situ* remelted by

Table 2
Selected processing parameters.

Parameter	Value
Argon flow rate (L/min)	50
Hydrogen flow rate (L/min)	8
Powder feed rate (g/min)	30–45[a]
Feedstock carrier gas flow rate (Ar) (L/min)	1.4
Feedstock injector tip location from gun centerline axis (mm)	6
Spray step (mm)	3.5–4.5[a]
Spray velocity (m/min)	75
Arc current intensity (A)	580
Feedstock injector diameter (mm)	1.8
Area exposed to plasma spray (mm^2)	30
Area exposed to combined treatment (mm^2)	1.6
Spray distance (mm)	120
Irradiation distance (mm)	70
Distance between powder impact and laser irradiation (mm)	22
α (°)	13

[a] Powder feed rate was adjusted according to the spray velocity to keep constant the average deposited thickness per pass. The spray step was adjusted according to the laser energy density to keep constant the laser-treated area per spray pass.

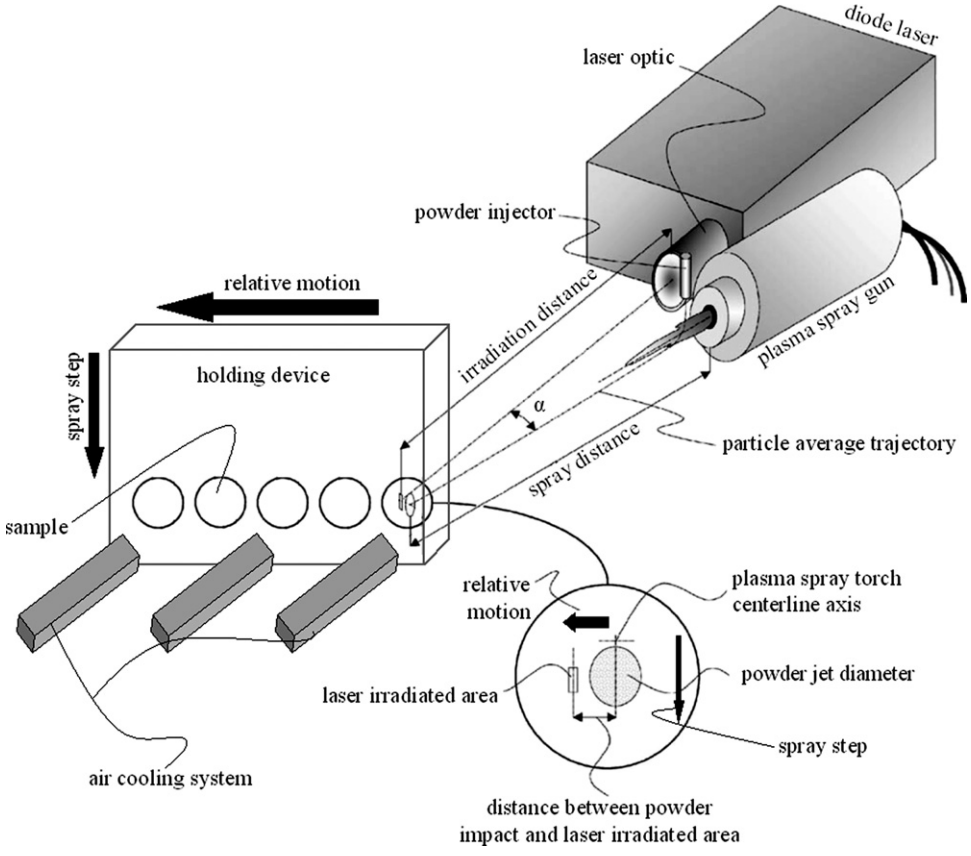

Fig. 1. Experimental device constituted by the combination of a plasma spray gun and a diode laser.