Available online at www.sciencedirect.com
ScienceDirect
Surface & Coatings Technology 202 (2008) 4479–4482
SURFACE & COATINGS TECHNOLOGY
www.elsevier.com/locate/surfcoat

In-flight particle characteristics control by implementing a fuzzy logic controller

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Available online 10 April 2008

Abstract

An approach based on a fuzzy logic controller was implemented to control and regulate the atmospheric plasma spray processing parameters (arc current intensity, total plasma gas flow, hydrogen content) to the in-flight particle characteristics (average surface temperature and velocity). The specific case of predicting plasma power spray process parameters to manufacture grey alumina (Al_2O_3–TiO_2, 13% by wt.) coatings was considered. This composition was selected due on the one hand to the large literature depicting coating characteristics and on the other one to pre-existing databases. The influence of the plasma spray process on the in-flight particle characteristics was investigated in order to build the experimental database.

Keywords: Plasma spraying; Process control; Article intelligience; Artificial neural network; Fuzzy logic; In-flight particle characteristic

1. Introduction

Atmospheric plasma spray (APS) process is usually optimized and controlled by conducting experiments aiming at varying several operating parameters followed by quantification of the microstructure and properties of the coatings. This rather "heavy" optimization strategy requires the analyses and controls of an important number of parameters. In parallel, several techniques are used to monitor the effects of process parameters on the in-flight particle characteristics (average surface temperature and velocity, mostly) during spraying and most of them lead to feedback models controlling the regularity of the industrial coating process [1,2]. Nevertheless, some parameters (intrinsic), such as electrode wear and arc root fluctuations are difficult to predict and control [3] whereas they have very significant effects on in-flight particle characteristics [4]. This work aims at studying the feasibility to implement a fuzzy logic controller to stabilize the in-flight particle characteristics to reference values by adjusting power parameters taking into account the process fluctuations. This strategy would make it possible to transfer the process control from the spray parameters to the in-flight particle characteristics.

The major steps to reach this objective are: i) to diagnose in-flight particle characteristics; ii) to identify the effects of operating parameters process parameters on the particle behavior; and iii) to stabilize in-flight particles characteristics to reference values by constantly adjusting power process parameters whatever the fluctuations (Fig. 1).

2. Experimental investigation

Metco 130 grey alumina (Al_2O_3–TiO_2, 13% by wt.) of 35.7 μm average diameter was used as a feedstock material. This composition was selected due on the one hand to the large literature depicting coating characteristics and on the other one to pre-existing databases.

Experiments were performed using a F4 plasma torch (Sulzer-Metco, Wohlen, Switzerland) equipped with a 6 mm internal diameter nozzle. A binary plasma gas mixture made of argon (primary plasma forming gas) and hydrogen (secondary plasma forming gas) was considered to conduct the experiments. Three power parameters were considered and varied: the arc current intensity, the total plasma gas mass flow rate and the

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0257-8972/$ - see front matter
doi:10.1016/j.surfcoat.2008.04.030

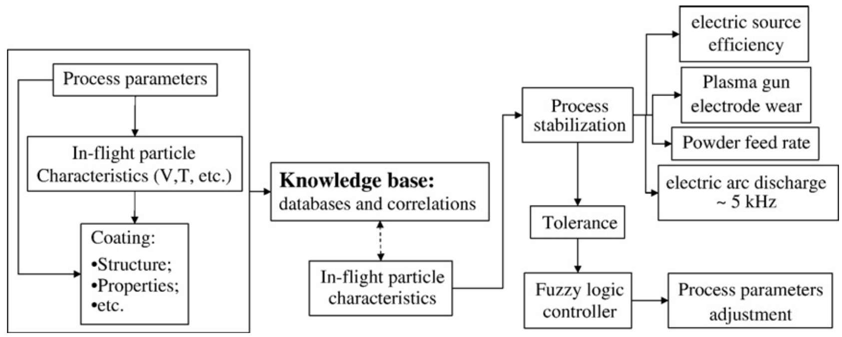

Fig. 1. Principle of the fluctuations control in APS process by an intelligent system.

hydrogen content. The effect of each parameter was study separately by fixing the others to constant values.

The particles were injected at the exit of the nozzle perpendicularly to the plasma jet axis. The injection distance from the injector tip to the torch centerline axis was 6 mm, the injector internal diameter 1.8 mm, the feedstock rate 22 g min^{-1}, the scanning step 12 mm per pass, the spray distance 125 mm and the spray angle normal to the substrate surface. The carrier gas flow rate was adjusted specifically for each parameter set in order to obtain an optimal particle trajectory within the plasma flow (*i.e.*, penetration of the particles in to hot core of the flow and resulting deviation angle of about 4 deg) using the Spray and Deposit Control system (SPCTS, University of Limoges, France).

In-flight particle characteristics were monitored in the absence of substrate using a SprayWatch system (Oseir Ltd., Tampere, Finland) at a distance corresponding to the spray distance. SprayWatch is an optical camera based system that uses a high-resolution, 12-bit fast shutter CCD array camera to create digital images of the spray pattern and to measure particle properties (*i.e.*, particle flux, velocity, average surface temperature, etc.). The system uses time-of-flight method for the particle velocity measurement. Indeed, the length of the particle trace on the CCD detector is measured by the image processing algorithm and is then converted to velocity by dividing by known camera shutter time. In the same time, the particle temperature is measured by two-color pyrometry. An optical double-stripe filter is integrated in the camera and covers a part of the CCD detector. The spray is imaged on the CCD in two different wavelengths so that the lateral distribution of the average particle surface temperature in the spray pattern could be calculated using calibration information.

Diagnostics considered 60 images for each operating parameter set and the corresponding values were then adjusted and averaged. Results are displayed in Table 1.

3. Results and discussion

3.1. Controller model

The purpose of the control based of Fuzzy Logic (FL) is to vary the behavior of a system by changing inputs of this system according to a rule or a set of rules that model how the system operates [5]. The developed system is based on Mamdani's fuzzy logic controller [6]. The primary interest of this approach is to code the desired behaviors in the form of rules expressed in a language close to the human language (witch take account concepts of uncertainty, imprecision, imperfection, etc.). The rules are in the familiar *if–then* format, and formally the if-side is called the *condition* and the then-side is called the *conclusion*. The model is able to execute the rules and compute a control signal depending on the measured inputs *errors* and *change-in-error*.

The following depicts block by block the diagram displayed in Fig. 2. The first block is dedicated to fuzzification which converts each input data to degrees of membership by a lookup in one or several membership functions (MF). The fuzzification block thus matches the input data with the conditions of the rules to determine how well the condition of each rule matches that particular input instance. There is a degree of membership for each linguistic term

Table 1
In-flight particle surface temperature and velocity at spray distance (EXP: experimental data, FL: predicted data by fuzzy logic controller)

Arc current intensity I [A]	Total plasma gas flow V_{Ar+H_2} [Nl min^{-1}]	Hydrogen volume content $V_{H_2/Ar}$ [%]	In-flight particle average surface temperature T [°C]		In-flight particle average velocity V [m s^{-1}]	
			T_{EXP}	T_{FL}	V_{EXP}	V_{FL}
350	50.0	25	2318	2330	264	265
450	50.0	25	2421	2420	285	286
530	50.0	25	2458	2460	302	300
600	51.9	30	2516	–	307	–
650	50.0	25	2515	2560	324	324
700	43.0	7.6	2396	–	336	–
530	34.6	25	2415	2420	251	260
530	41.5	25	2429	2420	270	268
530	55.3	25	2433	2430	313	311
530	62.2	25	2433	2430	311	327
530	69.1	25	2419	2420	348	332
530	42.4	5	2302	2330	267	280
530	44.3	10	2357	2350	299	288
530	46.2	15	2389	2380	303	299
530	48.1	20	2409	2410	301	301
530	51.9	30	2441	2440	299	299