Applied effect of Fe-based remanufacturing coatings after orthogonal optimization of spraying parameters

Zhong-yu Piao [12], Bin-shi Xu [2], Hai-dou Wang [2], Chun-huan Pu [2]
(1. YanShan University, School of Mechanical Engineering, Qinhuangdao 066004, China
2. National Key Laboratory for Remanufacturing, Beijing 100072, China)
Email:pzy0528@hotmail.com

Abstract

In this paper, the parameters of supersonic plasma spraying Fe-based coatings were optimized according to orthogonal design method, 9 orthogonal experiments were conducted. The microstructure of the coating was characterized by using SEM and XRD, the porosity and micro-hardness of the coatings was measured respectively. The results showed that spraying parameters play an important role on the properties of the coatings. The optimal spraying parameters were obtained by analyzing synthesis properties of coatings by means of synthesis point method. The orthogonal optimization results were verified to be perfect by conducting supplementary experiments.

Key words: Plasma spraying; Fe-based coating; Orthogonal optimization; Spraying parameter.

1 Introduction

The plasma spraying technology is one of mature thermal spraying technologies. In the plasma spraying process, the high temperature plasma flame can be obtained to melt various spraying materials by means of the gas ionizing, there is no limit for sprayed materials, so the plasma spraying technology is acceptable in many regions [1]. High efficiency supersonic plasma spraying device developed by national key laboratory for remanufacturing can realize supersonic plasma spraying under low energy consumption [2]. Fe-based self-fluxing alloy as a potential sprayed material for broad source and cheap price, can substitute expensive Co-based alloy, Ni-based alloy and ceramic materials for its wear-resisting property in low temperature [3,4]. For different sprayed materials, the using spraying parameters may be different relatively. The appropriate spraying parameters are precondition which the spraying coatings hold the excellent properties. Therefore it is necessary to optimize the spraying parameters. Orthogonal design as a partial factor design method can be applied in multi-factor experiments. In this process, the partial typical factors are picked out to conduct orthogonal experiments, and the results can be obtained under shorter experimental period and lower consumption. So orthogonal design experiment is an effective approach to optimize the spraying parameters [5]. In this paper, the spraying parameters of supersonic plasma spraying Fe-based coatings were optimized based on orthogonal experiments.

2 Orthogonal experiments

2.1 Factors and levels of orthogonal experiments

The objective of the orthogonal experiments is that some typical factors of experiments are picked out and then the best factor combinations are obtained by designing the factor levels properly. The spraying parameters are orthogonal factors for supersonic plasma spraying, the qualities of coatings are influenced by many factors such as spraying distance, spraying current, spraying voltage, powder feed rate, size and shape of powder et al. These factors influenced the kinetic energy and thermal energy of the melting particles in the spraying process, unsuitable kinetic energy and thermal energy would induce decline of coatings properties [6-8]. Spraying distance can remarkably influence the molten condition of particles as arriving surface of substrate, spraying current can remarkably influence the temperature of plasma flame, spraying voltage depended by secondary gas flow rate can remarkably influence the increment of thermal enthalpy. So spraying distance, spraying current and spraying voltage as the typical factors were picked out to be factors of orthogonal experiments in this study, 3 levels of each factor were given respectively. 3 factors and 3 levels orthogonal experiment was conducted, the factors and levels of orthogonal experiment were presented in table 1.

Table 1 Factors and levels of orthogonal experiments

Factors of experiments	Spraying distance(mm)	Spraying current(A)	Spraying voltage(V)
Level 1	100	340	140
Level 2	110	360	150
Level 3	120	380	160

2.2 Specimens of orthogonal experiments preparation

Fe-based self-fluxing nature alloy was used as spraying material, the composition of alloy was presented in table 2. The diameter of powder was 30-40 μm, the sizes and shapes of powders characterized by using SEM were presented in Fig.1. For the round powders had excellent flowing property and epigranular as showed in Fig.1, they were fit for spraying [9,10]. A commercial middle carbon steel was used as substrate, the length, width and height of substrate were kept to 30mm, 15mm and 5mm, respectively. Substrates were cleaned in acetone solution and sandblasted by using corundum powder before spraying process to insure surface clearness and roughness.

Table 2 Composition of Fe-based alloy

Element	C	Cr	B	Si	Fe
Mass percent (wt%)	0.16	13.6	1.6	1.1	Balance

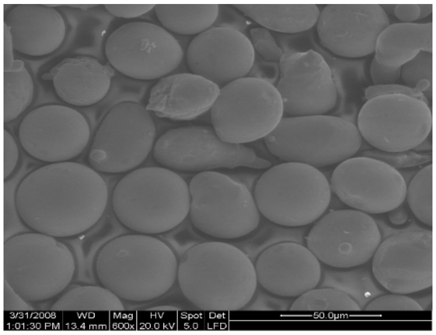

Fig.1 Shapes of Fe-based alloy powders

Supersonic plasma spraying was used to deposit the coatings, the spraying gun was showed in Fig.2, the nozzle of spraying gun inclined right aiming for carrying the alloy powders to low temperature region of plasma flame to avoid atomization of alloy powders because of superfusion. In spraying process, argon gas was used as primary gas and hydrogen gas as secondary gas. The flow of primary gas and powder feed rate were confirmed as constant factors in this paper, 9 orthogonal experiments were obtained according to orthogonal design of spraying distance, spraying current, spraying voltage, and the thickness of deposited coatings were 200µm. The orthogonal experiments table designed according to orthogonal design criterion was showed in Table 3.

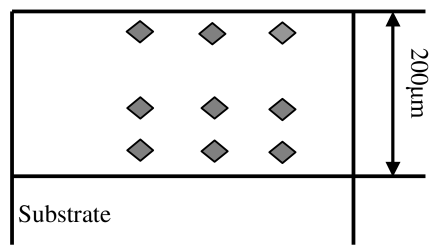

Fig. 3 Distribution of the measuring points

Table 3 Orthogonal experiment table of spraying parameters

Number of sample	Experiment parameters					
	Flow of Ar gas	Spaying distance	Spraying current	Spraying voltage	Powder feed rate	Coating thickness
1	3.4 m^3/h	100mm	340A	140V	30g/min	200µm
2	3.4 m^3/h	100mm	360A	150V	30g/min	200µm
3	3.4 m^3/h	100mm	380A	160V	30g/min	200µm
4	3.4 m^3/h	110mm	340A	150V	30g/min	200µm
5	3.4 m^3/h	110mm	360A	160V	30g/min	200µm
6	3.4 m^3/h	110mm	380A	140V	30g/min	200µm
7	3.4 m^3/h	120mm	340A	160V	30g/min	200µm
8	3.4 m^3/h	120mm	360A	140V	30g/min	200µm
9	3.4 m^3/h	120mm	380A	150V	30g/min	200µm

2.3Analysis of coatings

2.3.1 Measurement of porosity

The microstructure of coatings was characterized by using FEI Quanta200 SEM, SEM images with a magnification 800× were taken from each coating cross-section. The high-magnification images allowed a closer view of the pore structure as well as the micro-crack distribution [11]. A new image analysis method (IAM) was used to evaluate the porosity of coating, the areas of pore structure and micro-crack length were showed in two-dimension plane through gray level transformation. The procedure of determination of the coating porosity using the proposed IAM can be divided into following four steps, i.e., collection and import of SEM images, gray level transformation, fuzzy enhancement, identification of pores and micro-cracks [12]. For the randomness of pores distribution, 15 SEM images were randomly to measure the porosity, respectively. The arithmetical mean of measurements was the coating porosity.

2.3.2 Measurement of micro-hardness

Vickers-hardness of coating was measured at the polished coating surface by HVS-1000 micro-hardness tester (with load 100g and loading time 15s). For the measurement value of coating micro-hardness would be influenced by layer structure and pore, the measuring points were showed in Fig.3. The arithmetical mean of all measuring points was value of coating micro-hardness.

3 Analysis of orthogonal experiments

3.1 Orthogonal analysis of porosity and micro-hardness of coating

The service life of wear-resisting coating is contacted to the micro-hardness and porosity of coating, so the micro-hardness and porosity were used as evaluation

```
ERROR: rangecheck
OFFENDING COMMAND: .buildcmap

STACK:

-dictionary-
/WinCharSetFFFF-VTT25EFF69Dt
/CMap
-dictionary-
/WinCharSetFFFF-VTT25EFF69Dt
```