Rare Metal Materials and Engineering
Volume 43, Issue 10, October 2014
Online English edition of the Chinese language journal

Available online at www.sciencedirect.com
ScienceDirect

Cite this article as: Rare Metal Materials and Engineering, 2014, 43(10): 2349-2353.

ARTICLE

Effect of the Process Parameters on the Indentation Size of Particle Deposited Using Supersonic Laser Deposition

Lu Yuanhang[1], Yuan Linjiang[1], Cai Dingbao[1], Luo Fang[1,2]

[1] Key Laboratory of Special Purpose Equipment and Advanced Processing Technology, Ministry of Education, Zhejiang University of Technology, Hangzhou 310014, China; [2] College of Zhejiang, Zhejiang University of Technology, Hangzhou 310024, China

Abstract: Single Stellite 6 particle was selected as research unit, the impacting characteristic of the particles, deposited on medium carbon steel using supersonic laser deposition (SLD) was studied by the finite element method (FEM), such as the depth and width of the indentation, the temperature and the sizes of impacting particles, and the substrate temperature. Through extracting the coordinate values of the deposition unit, the depth and the width of indentation were obtained after the particle impacted the substrate. Then, the breadth depth ratio was used to analyze the effective range where the particles can be effectively deposited and fitted value. The result shows that the breadth depth ratio range where the particles can be effectively deposited is 1.3~1.5.

Key words: supersonic laser deposition (SLD); breadth depth ratio; numerical fitting

Supersonic Laser Deposition (SLD) technology[1-3] is an attractive coating technology which is based on the cold spraying technology[4-6]. Compared with the cold spraying technology, the substrate is heated by the laser beam during the spray process, namely powder deposition spot coincides with the laser spot and keeps synchronous movement. So, SLD offers a potential of combining the advantages of cold spray, such as solid-state deposition, high builds rate, low oxidation, high deposition velocity and the ability to deposit a wide range of wearing and corrosion-resistant materials[7], which overcomes some shortcomings for instance the cold spraying technology can't deposit the brittle material and the high hardness material (such as ceramic)[1]. Therefore, SLD has great attraction and is a selective compound technology. However, in view of the instantaneity characteristics of the high-speed particle collisions on the substrate, it is unable to observe the deformation process directly. Thus, the behavior of particle impact has been studied using numerical simulation and experiment[8,9]. Nonetheless, the work is just to be limited in the cold spray.

This paper presents the effect of the process parameters on characteristics of Stellite 6 particles deposited on the steel using SLD by means of finite element analysis (FEA), analyzes the numerical changes of the width and depth of particle deposit indentation, and the breadth depth ratio range of the particle which can be effectively deposited.

1 Numerical Simulation

1.1 Numerical calculation method

The deformation behaviors of particles impacting on substrate were simulated using the software package ANSYS Multiphysics/LS-DYNA. In order to facilitate the simulation of dynamic process of particle impact on the substrate, the single Stellite 6 particle was chosen as research unit. Considering that the high speed impacting process is mainly controlled by the inertial force, gravity force and other bulk force could be presumed to neglect. During the simulation, in order to ensure the calculation accuracy of deformation area, a 3D quarter model of single particle impacting on substrate was simulated with Lagrangian formulation, and in consideration of the computing time and calculation accuracy problem, the meshing of the deformation area was subdivided to ensure the

Received date: October 11, 2013
Foundation item: National Natural Science Foundation of China (51271170); China International Science and Technology Cooperation Project (2011DFR50540); Major Scientific and Technological Special Key Industrial Project of Zhejiang Province (2012C11001)
Corresponding author: Luo Fang, Associate Professor, College of Zhijiang, Zhejiang University of Technology, Hangzhou 310024, P. R. China, E-mail: luofang@zjut.edu.cn

calculation accuracy. The size of the collision zone is 2 μm. The model and meshing are shown in Fig.1.

1.2 Material model

During the particle impact process, the material model plays a critical role in the accuracy of the numerical analysis output. Because of the instantaneity of particle impact duration, different substrate temperatures result in large plastic deformation and so on; hence, the classic bilinear isotropic hardening model was chosen to implement the numerical simulation, which is the Von-Mises plastic yield criterion, and the strain and stress characteristics of the material are depicted by plastic slope and elastic modulus. In the criterion, the yield stress of the material can be seen to nothing with the pressure, and thus the yield strength σ_Y can be described by Eq. (1) [10].

$$\sigma_Y = \sigma_0 + E_p \varepsilon_{eff}^p \tag{1}$$

where, σ_0 is initial yield stress, ε_{eff}^p is effective plastic strain and E_p is plastic hardening modulus. ε_{eff}^p and E_p can be computed by following Eq. (2) and (3) [10]:

$$\varepsilon_{eff}^p = \int_0^t d\varepsilon_{eff}^p \tag{2}$$

$$E_p = \frac{E_{tan} E}{E - E_{tan}} \tag{3}$$

In which, $d\varepsilon_{eff}^p = \sqrt{\frac{2}{3} d\varepsilon_{ij}^p d\varepsilon_{ij}^p}$, E is Young's modulus, and E_{tan} is tangent modulus.

1.3 Numerical calculation process and parameters

During the SLD simulation, the working gas was N_2. The gas pressure was 3×10^6 Pa and gas temperature was 450 °C. Simulation parameters of the steel are given in Table 1. Satellite 6 yield strength is 480 MPa, young's modulus is 207 GPa, tangent modulus is 900 MPa and poisson's ratio is 0.34 μ.

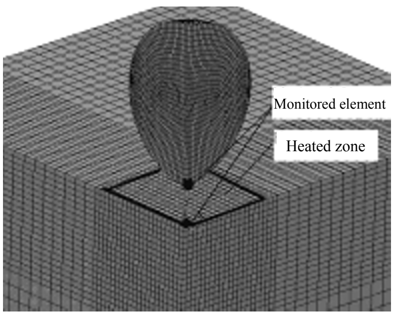

Fig.1 Model of simulation

Table 1 Thermal physical parameter of steel used in this study

Temperature/°C	400	850	1000	1100	1150	1200
Density/kg·m^{-3}	7850					
Poisson's ratio/μ	0.33					
Young's modulus/GPa	188	118	112	100	95	90
Yield strength/MPa	350	193	119	85	71	60
Tangent modulus/MPa	500	400	305	200	183	82

2 Results and Discussion

2.1 Morphology analysis of particle deposition

Fig.2 presents six deformation morphologies of particle impacting on substrate under the following conditions: the constant impact velocity, gas pressure of 3×10^6 Pa, particle diameter of 35 μm, particle and gas temperature of 450 °C and different deposition temperatures, showing deformation characteristics of the particle and substrate upon the particle impact on the substrate at 180 ns. Fig.2a presents the deformation morphology of the particle impact on the substrate at room temperature. It can be seen that the particle has a large deformation from a sphere to an ellipse, and the deformation indentation of the substrate is the smallest. Therefore, the particle is difficult to be deposited on the substrate. From Fig.2b and Fig.2c, it is clear to see that the deposition indentation is still shallow in spite of the fact that the particle has the larger deformation. When the deposition temperature is 500 °C, the value of effective stress on the substrate is quite large after particle impact. This factor makes the particle unable to be bonded with substrate effectively. Fig.2d and Fig.2e show a good match between the particle deformation and the substrate deformation. The degree of the particle deformation and the depth of deposition indentation in Fig.2e are greater than those of Fig.2d. Those results show that suitable deformation between the particle and the substrate can reduce the porosity rate of coating under a certain condition.

The particle and the substrate with good adhesion can be seen from Fig.3[3] which is the cross-section morphology of the optimization deposition layer prepared at 1100 °C and the deposition velocity of 450 m/s, and the average thickness of the deposited layer is 0.135 mm. The interface between the coating particle and the substrate presents good bonding.

In order to compare the deposition morphology of Fig.2e, special simulation was done to analyze the deposition morphology. The deposition conditions were as follows: the particle temperature of 20 °C and the substrate temperature of 1200 °C (see Fig.2f). This analysis shows that the higher the laser treatment temperature is, the lower the strength of the substrate is. Meanwhile, the deposition indentation becomes large and the maximum deposition indentation will increase the coating porosity.

2.2 Analysis of indentation size at particle deposition

The contours of the result displacement of the particle deposited at 180 ns and different substrate temperatures are illustrated in Fig.4, which represent the result displacement evolution of the substrates. For example, Fig.4e, 4f present a great change of the result displacement of particle deposition, which isn't propitious to improve the binding rate between them.

The width and depth of the deposition indentation can be obtained when the single particle impacts the substrate by