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Effect of rare earth oxide on the properties of laser cladding layer and machining vibration suppressing in side milling

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ABSTRACT

Laser cladding, which can increase the hardness and wear resistance of the used components, is widely used in remanufacture and sustainable manufacturing field. Generally, laser cladding layer should to be machined to meet the function as well as the assembly requirements. Milling is an effective mean for precision machining. However, there exist great differences of physical and mechanical performances between laser cladding layer and substrate material, including microstructure, hardness, wear resistance, etc. This produces some new milling problems for laser cladding layer, such as machining vibration which may lead to low productivity and worse surface integrity. Thus, it is necessary to develop a novel laser cladding powder which can improve the surface hardness and wear resistance, while reducing the machining vibration in milling. Laser cladding layer was prepared by FeCr alloy and La_2O_3 mixed powder. The effect of La_2O_3 on the coating properties was investigated. Signal analysis methods of the time and frequency domain were used to evaluate the effect of the La_2O_3 on machining vibration in the side milling laser cladding layer. The key findings of this study are: (a) with the La_2O_3 content increasing, the grain size decreases dramatically and the microstructure of laser cladding layer are refine; (b) the hardness and wear resistance of the coatings with La_2O_3 are improved significantly; and (c) the machining vibrations of laser cladding layer with La_2O_3 are obviously reduced and the chatter is effectively avoided occurring.

1. Introduction

Remanufacture, as the ultimate form of recycling, can restore the used products of high value-added into like-new condition and get great benefits of energy-saving and emission reduction [1]. Laser cladding has been defined as a surface-coating technique which makes use of material with superior physical and chemical properties to protect the substrate from corrosion and abrasive wear even at extreme conditions during service [2,3]. Therefore, laser cladding has been developed for many years as a remanufacturing and sustainable manufacturing technique in industry [4,5].

Generally, laser cladding layer (LCL) should to be machined to meet the function as well as the assembly requirements. Milling is an effective means of precision machining. However, there exist great differences of physical and mechanical performances between LCL and substrate material, including microstructure, hardness, wear resistance, etc. This produces some new milling problems for laser cladding layer, such as high machining vibration, which may lead to low productivity and worse surface integrity. Thus, it is of great importance to develop a novel laser cladding powder which can improve the surface hardness and wear resistance while reducing machining vibration in side milling.

1.1. Effect of rare earth and oxides

Recently, considerable attention was focused on rare earth (La, Ce and its oxide) which can modify the properties of laser cladding layer. Wang et al. [6] studied the effects of La_2O_3 on the microstructure and wear resistance of laser clad nickel-based alloy coating and reported that the microstructure was refined and the wear resistance of coating was enhanced significantly. Hao et al. [7] investigated the effects of rare earth oxide on the hardfacing metal microstructure of medium carbon steel and pointed out that the microstructure was refined at first and then coarsened with the increase in rare earth oxide addition. In situ Fe–NbC composite laser cladding layer with different CeO_2 addition was produced in die steel by Li et al. [8], and it is shown that CeO_2 plays important roles in reducing microporosities, refining grains and improving the precipitation of NbC. Golmakaniyoon et al. [9] found that the creep

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Table 1
Chemical composition of substrate and laser cladding powder (%).

Chemical element	C	Mn	Si	Mo	Cr	Ni	Cu≤	P≤	S≤	B≤	Fe
KMN	0.13–0.18	0.5–0.8	0.17–0.37	0.9–1.1	2.2–2.5	–	0.30	0.030	0.030	–	Balance
FeCr alloy powder	0.15	–	1.1	1.0	17.35	1.35	–	–	–	1.26	Balance

strength of the Mg–6Zn–3Cu cast alloy was remarkably improved by RE addition. Lu et al. [10] investigated the effect of Ce addition on the mechanical properties and damping behavior of the Cu–Al–Mn shape memory alloys and reported that with increase in the Ce content, the damping capacity increases initially and then decreases. Wang et al. [11,12] reported that the damping capacity of Mg–Cu–Mn alloys and ZK60 magnesium alloys improved abnormally with the earth element addition.

1.2. Machining vibration

Machining vibration is one of the key factors influencing the quality of the machined surface, tool life and process stability. Choudhury and Sharath [13] pointed out that the vibration of cutting process was one of the major factors limiting its performance and provided an on-line control system of machine tool vibration during turning operation. Dimla Sr. and Lister [14] investigated the on-line metal-cutting tool condition monitoring by vibration analyses and reported that the analyses in time and frequency domains showed some components of the measured signals to correlate well with the accrued tool wear.

Many researchers have been looking for the methods of suppressing vibration/chatter in the cutting process. Vibration/chatter control or suppression techniques can be classified into two main categories, namely passive chatter suppression/control and active chatter suppression/control. In the passive technique, the objective is to suppress chatter by changing the system behavior. The system behavior can be changed or modified by either improving the design of the machine tool or by using additional devices that can absorb extra energy or disrupt the regenerative effect [15]. In 1965, Slavicek [16] proposed a variable-pitch cutter design idea for chatter suppression. Huang et al. [17] investigated the vibration reduction mechanism of variable-pitch end mills and found that the variable-pitch mill can reduce the forced vibration in the cutting process. Ema and Etsuo [18] improved the damping capability of boring tools and suppression of chatter vibration using impact dampers. Yang et al. [19] presented a design and optimal tuning of multiple tuned mass dampers (TMDs) to increase chatter resistance of machine tool structures. In the active technique, as the name suggests, chatter vibrations are actively eliminated by continuous monitoring and diagnosis of the turning process and by executing necessary changes in the process [20]. Lin and Hu [21] proposed an approach in which the feed-rate and spindle speed were varied to suppress chatter. Frumusanu et al. [22] developed a stable intelligent control technique for turning and the technique involved online monitoring of the cutting force signal. Emad Al-Regib et al. [23] presented a method for programming spindle speed variation for machine tool chatter suppression and verified the effectiveness experimentally.

The literature review shows that very few studies have concentrated on the characteristics of machining vibration of laser cladding layer. The bulk study on the effect of rare earth is limited to the material characteristics of laser cladding layer. And the effect of rare earth on damping capacity is limited to the shape memory alloys and magnesium alloys. The vibration/chatter suppression techniques only focus on the machining systems behavior or executing necessary parameters changing in the process. The effect of damping capacity of materials itself on the vibration suppression has not been investigated. And the effect of rare earth on vibration suppressing of laser cladding layer in side milling has not been addressed. The objective of this study is to fill in the knowledge gap and solve the impressing issues of vibration suppressing in laser cladding layer milling process.

1.3. Scope of this research

In this work, FeCr alloy powder with La_2O_3 was deposited on KMN steel plates by CO_2 laser. The microstructures, phase constitution, hardness and wear resistance of coating were investigated. The machining experiments were performed under dry milling of LCL, which can be regarded as a novel material in the processing field. Signal analysis methods of the time and frequency domain were used to evaluate the effect of the La_2O_3 on machining vibration in side milling. Further, the variation in surface roughness with the weight fraction changing of La_2O_3 was presented in this article.

2. Experimental setup

2.1. Laser cladding experiment and coating performance analysis

FeCr alloy powder, whose particles were from 26 to 38 μm in size, was used in this study. La_2O_3 powder was added into the mixture with different mass fractions. The compositions of the alloy mixture and the mass percent of laser cladding powders are indicated in Tables 1 and 2, respectively. According to the ratio of the weight fraction, FeCr alloy and La_2O_3 powder were mixed and prepared by ball milling with 72 h. KMN steel is high-strength low-alloy steel developed by Shenyang Blower Works Group Corporation, China. And KMN steel is commonly used in large centrifugal compressor impeller manufacturing. The KMN steel specimen was machined into a rectangular block. The chemical composition and dimensions of the substrate are shown in Tables 1 and 3, respectively. The surface of the substrates was polished and rinsed with acetone prior to cladding. The laser cladding process was performed using a CO_2 multimode cross-flow laser operating at output power of 6 kW with a 3 mm beam diameter. The beam scanning speed was 500 mm/min. Fig. 1 shows the schematic illustration of laser cladding.

The microstructures of LCL were studied by means of scanning electron microscopy (SEM). Samples for SEM observation were prepared using standard mechanical polishing procedures

Table 2
Compositions of the cladding powders (wt%).

No.	FeCr alloy	La_2O_3
1	100	0
2	99.5	0.5
3	99.0	1.0
4	98.5	1.5
5	98.0	2.0

Table 3
The dimensions of substrate and cladding layer.

	Dimension (mm)		
	Length	Wide	Height
Substrate	50	78	5
Cladding layer	40	20	2