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Development and qualification of a novel laser-cladding head with integrated sensors

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Abstract

A compact laser-cladding head with integrated sensors and coaxial powder feeding was developed and qualified for industrial applications. Different sensors were integrated in the head for monitoring the optical components and for monitoring and controlling the laser cladding process. The operating status of the dichroitic beam splitter, the protective glass and the powder-feeding nozzle could be acquired in real time. The process monitoring and control based on the infrared temperature signal were adopted in order to ensure high product quality and reproducibility. These characteristics guarantee the application of the cladding head in industrial environments and for automated production.

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Keywords: Laser cladding; Cladding head; Component monitoring; Process monitoring and control

1. Introduction

Laser cladding has been widely adopted to provide wear and corrosion resistant layers on machine parts [1,2], to repair and modify costly worn parts like injection molds and turbine components and to process distortion vulnerable components [3–6]. This technology has also found a new and promising application in direct building of three-dimensional metal parts [6–11]. Laser cladding can be classified as a two-stage process with pre-placed additional material and a one-stage process with in-situ fed material in the form of powder or wire. In the one-stage process, the additional materials can be fed into the melt pool either laterally or coaxially to the laser beam. Cladding with coaxial powder feeding prevails over other methods, because this feeding method guarantees a multidirectional and more flexible process [12]. The powders with a typical diameter of 20–150 μm are fed through a coaxial powder nozzle by the carrier gas (e.g. Ar, He) into the melt pool. The gas also has the function of a shielding gas to prevent the clad layer from oxidation. The laser beam melts a thin layer of the work piece (in the 100 μm range) and the fed powder simultaneously. Thus the melted powder and the base material are metallurgically bonded with up to 100% density. Because the heat input is limited to the local area, which results from the good focusability of the laser beam, only very little heat is applied to the base material. As a result, a small heat affected zone (HAZ) and low dilution can be achieved. Typical depth of the HAZ ranges from a few hundred microns to 1 mm [3].

For laser cladding with coaxial powder feeding, a cladding head is necessary to guide and focus both the laser beam and the powder jet simultaneously on the surface of the work piece. A good cladding head suitable for industrial applications must be robust enough to guarantee an accurately defined process, so that high product quality and reproducibility can be ensured. Normally, several optical components, such as a dichroitic beam splitter, focus lens and protective glass are integrated

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in the cladding head. During laser cladding with powder, these components are vulnerable to be soiled by the vaporized powder particles and smoke. A slight soiling can cause noticeable deterioration of the process, such as inhomogeneous distribution and losses of laser power and increasing absorption of laser radiation by the components. Thereby, the components will be overheated, and even worse, broken. Besides the optical components, the coaxial powder nozzle is another important component of the cladding head. It guarantees a homogeneous powder distribution in the powder focus, which is one of the most important criteria for achieving a good clad quality. When laser cladding over a long time and with high laser power, the components of the cladding head are exposed to high thermal load. Thus it is essential to monitor the operating status of the components online, in order to access their condition and avoid the deterioration in time.

Another important requirement for adopting this technology into the industry is to meet the increasing demands on product quality. The economic efficiency of the process can be significantly increased through the decreased scrap rate. Thus, a method to monitor and control the cladding process needs to be developed.

In comparison with laser welding, laser cladding is not widely adopted in the industry, while there are few commercial cladding heads available in the market. With this background, a unique laser-cladding head with integrated sensors was developed. Different sensors were integrated in the head for monitoring the operating status of the optical components and for monitoring and control of the laser-cladding process. The temperature of the beam splitter, protective glass and powder-feeding nozzle as well as the scattered laser light at the protective glass can be acquired in real time. Process monitoring and control based on the infrared (IR-) temperature signal was applied to guarantee product quality and reproducibility.

2. Design of the cladding head

Fig. 1 shows the configuration of the cladding head with optical components, a set of coaxial powder nozzles and sensors. The cladding head contains

- three contact thermometers for monitoring the temperature of the dichroitic beam splitter, the protective glass and the coaxial powder nozzle, respectively,
- two Nd:YAG photodiodes for measuring the output laser power and the scattered laser light at the protective glass, respectively,
- one germanium(Ge) photodiode for measuring the IR-temperature signal emitted from the melt pool,
- a CCD-camera for monitoring the cladding process coaxially.

The dichroitic beam splitter was placed in the cladding head at an angle of 45° to the laser beam. It was coated with a special film which had a transparency of 98.8% for

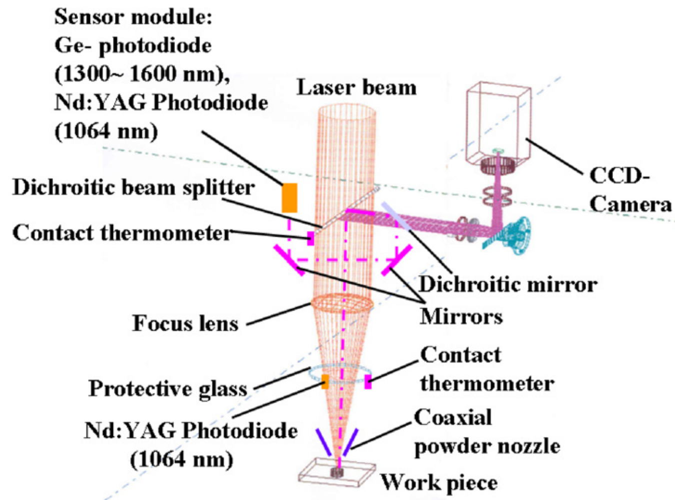

Fig. 1. Configuration of the cladding head.

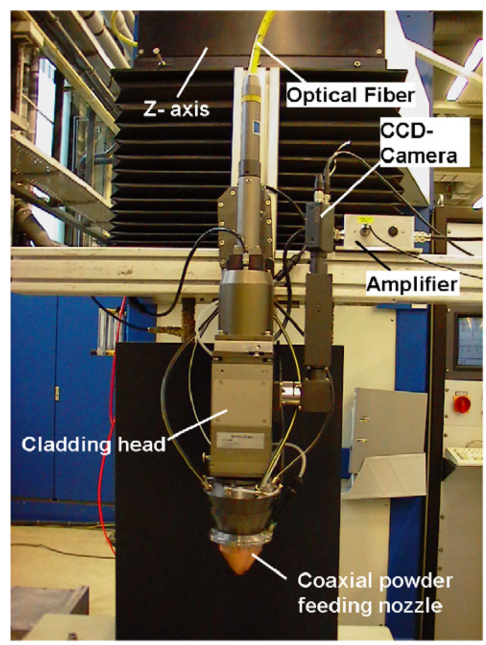

Fig. 2. Photo of the cladding head.

the 1064 nm Nd:YAG laser beam. The reflected laser power from the beam splitter was detected by a photodiode located in the sensor module. This signal was proportional to the original laser power signal. The IR-temperature signal emitted by the melt pool was detected by a Ge-photodiode. The dashed line shows the path of the signal from the melt pool to the sensor. Additionally, the melt pool can be monitored by the CCD camera. The ancillary lenses of all optical sensors were aligned coaxially to the laser beam, in order to eliminate the influence of the change of processing directions on the measurement.

Fig. 2 shows the cladding head mounted on a four-axis CNC handling system. A Nd:YAG laser with 3 kW output power and a focus lens with a 200 mm focal length were connected to the head. The measured signals were firstly linearly amplified and then transferred to a data processing