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Vision-sensing and bead width control of a single-bead multi-layer part: material and energy savings in GMAW-based rapid manufacturing

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ABSTRACT

Rapid manufacturing technologies have made it possible to reduce material wastes and to remanufacture valuable dies and tools. This paper focuses on reasonable utilization of materials and energies in gas metal arc welding (GMAW) for rapid manufacturing. During the weld-based additive manufacturing process, geometries of the deposited weld beads should be monitored and controlled. Using a composite filtering technique, a computer vision-sensing system was designed. Features of the weld bead image were analyzed. A corresponding image processing technology was used to extract parameters of the deposited weld beads. An on-line control of the deposited beads was realized based on a segmented neuron self-learning controller. The results show that the proposed control system is capable of keeping the deposited bead width of a thin-walled part consistent, making an efficient use of materials and energies possible.

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1. Introduction

In recent years, sustainable manufacturing is a research focus because of the urgency of decreasing material wastes and energy consumptions. Main concerns are related to the design of manufacturing process with the aim of conserving energies and materials or the utilization of the most proper forms for energies and materials (Jovane et al., 2008).

In this circumstance, additive net-shape rapid manufacturing has gained worldwide popularity for its capacity of reducing environmental burdens within materials manufacturing industry (Sutherland et al., 2003). Compared with the traditional removal process in forming components, rapid manufacturing is an additive layered manufacturing process by slicing the 3D geometric model into simple 2.5-dimensional layers (Karunakaran et al., 2010). Significant reductions in production costs and time between the original concept and final product, as well as materials saving are expected with this technique (Santos et al., 2006). By using only the quantity of the material needed, it is capable of decreasing energy consumption and industry scrap compared with conventional fabrication methods. Furthermore, it does not need specifically designed fixture or tooling, increasing the flexibility of the forming process and reducing the cost for fabricating special tools (Morrow et al., 2007).

With an increasing demand for building metallic tools, rapid manufacturing based on GMAW has shown new promises due to advantages of high production efficiency, simple equipment, high density and excellent bonding strength of parts (Mughal et al., 2006).

Generally, the GMAW-based rapid manufacturing process is composed of several procedures including establishment of 3D models of parts, slicing of desired thickness for each layer, design of welding paths and parameters in each layer, and stacking up of deposited weld beads layer by layer. However, the GMAW-based rapid manufacturing process consists of multi-layer depositions. Keeping the heat input as constant, when the number of the deposited beads increases, the deposited weld pool flows easily. The shape of each bead cannot be easily controlled because of serious heat accumulation, especially weld pool located at the boundaries of components. Moreover, bubbles and cavities may generate in the weld pool at high temperature due to an intense metallurgical reaction (Zhang et al., 2003). Thus, the control of heat input is of great importance for increasing the stability in layered deposition process.

At present, most of the works for increasing process stability are based on laser metal deposition (Tang and Landers, 2011; Heralic et al., 2012). To our knowledge little has been focused on the GMAW-based deposition. Several studies have been carried out for

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the control of heat input during the GMAW-based deposition process. Simple temperature control techniques were developed to decrease the heat input by means of an infra-red remote sensor (Spencer et al., 1998). The deposition did not resume until the part had cooled sufficiently. A projected spray transfer mode was established at low currents by wire electrode oscillation, enhancing the surface quality of weld beads for overlay cladding process (Wu and Kovacevic, 2002; Zhang and Li, 2001; Zhang et al., 1998). On the other hand, a novel hybrid approach, integrating GMAW as an additive and computer numerical control (CNC) milling as a subtractive technique, was developed to improve the surface quality and accuracy of solid freeform fabrication (SFF) parts (Suryakumar et al., 2011; Song and Park, 2006). Each layer was face milled by the CNC machining for removing scallops and stack up of errors, which resulted in material wastes and inefficiency of the process. Nevertheless, the essence of these approaches is an open-loop control.

This research aims at the reduction of material wastes and heat input consumptions during the layered deposition process. An online monitoring and control of the process was established through a passive vision-sensing system. The feasibility of the control system was evaluated through deposition of single-pass multi-layer thin walls. Section 2 presents the description of methods. Results and discussion are presented in Section 3. The last Section 4 ends the paper with some main conclusions.

2. Methods

2.1. Experimental system

2.1.1. The functional structure of GMAW-based rapid manufacturing system

The GMAW-based rapid manufacturing system is shown in Fig. 1, which included a three-dimensional welding flat (WF), a welding power supply (WPS), and a computer for sensing and control (CSC). The CSC was the key of the subsystem. It mainly realized three functions: control of the WPS and WF with a USB2813 data acquisition card, control of the vision-sensing system by means of an image acquisition card, and providing human–machine interface consisting of an image displaying and processing module, an arc on/off model, and a model for adjusting welding parameters.

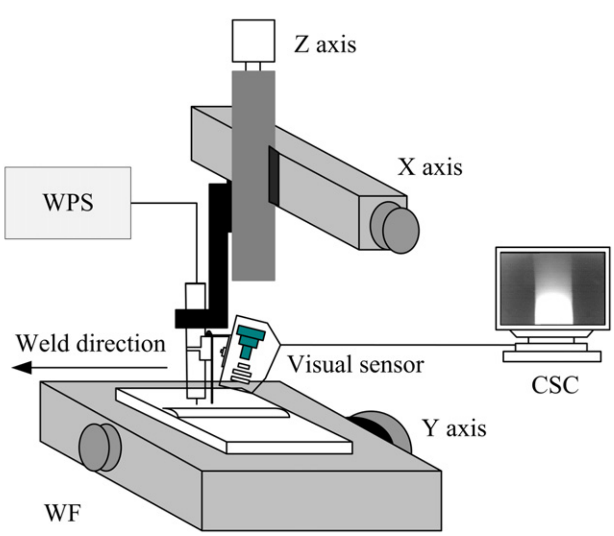

Fig. 1. The schematic diagram of GMAW-based rapid manufacturing system.

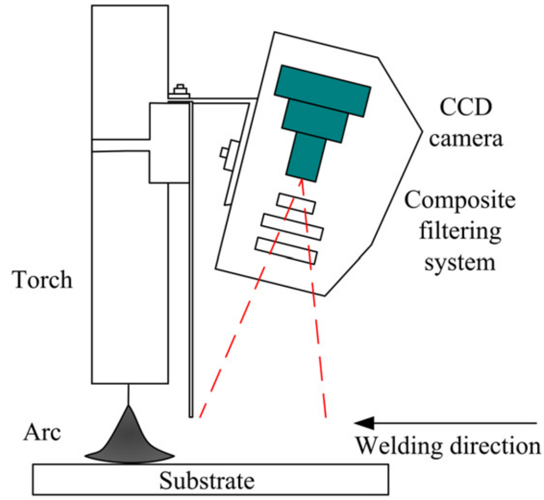

Fig. 2. Structure diagram of the visual sensor.

2.1.2. Visual sensor system design

Visual sensor system is of great significance for acquiring satisfactory weld bead images and improving detection precision in layered deposition process. The structure diagram of the visual sensor is shown in Fig. 2. Since the weld pool with high temperatures is still in liquid form under the welding torch, the deposited bead shape is uncertain. Thus, the visual sensor was fixed to the rear of the welding torch, and the minimum distance between the detection position and welding electrode was 18 mm with a certain lag, ensuring a solidified weld bead.

The sensor was composed of a neural-band filter, two neural-density filters, and a CCD camera. The attenuation of both neural-density filters was 99% and 90%, respectively. The selective center band of the narrow-band filter was 650 nm. This is because the deposited weld bead with extremely high temperature mainly emits infra-red radiations. In this case, its morphology can be clearly seen in the image. To obtain perfect weld bead images, a baffle plate was placed between the torch and the sensor for blocking strong arc light reflections.

2.2. Deposited weld bead image processing

A typical weld bead image with eight-bit grey scale is presented in Fig. 3, from which the deposited bead morphology can be clearly

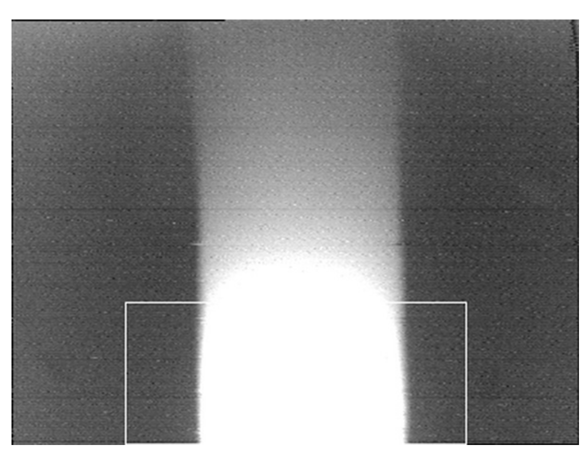

Fig. 3. Typical deposited weld bead image during GMAW-based rapid manufacturing.

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