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Experimental investigations into rapid prototyping of composites by novel hybrid deposition process

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Abstract

Solid Freeform Fabrication (SFF) gives engineers a new freedom to build parts that have been impossible to manufacture using conventional techniques. However, the surface finish and accuracy of SFF parts remain lower than those of parts that have been machined in conventional methods such as milling. A process combination of additive and subtractive techniques is currently being developed by our group at KIST to overcome this problem. The hybrid approach called “3D welding and milling” uses welding as an additive, and conventional milling as a subtractive technique. As part of this process development, two different building strategies have been developed to build multi-material parts directly. The results prove the applicability of the 3D welding and milling process for rapid prototyping of bimetallic parts. A significant potential application is for the rapid prototyping of injection mold inserts.

Keywords: Rapid prototyping; Multi-material part; Functionally Graded Material deposition (FGM); Gas Metal Arc Welding (GMAW)

1. Introduction

With an increasing demand for metallic prototypes and tools [1], several direct SFF techniques such as 3D Welding [2], Selective Laser Sintering (SLS) [3], Selective Laser Melting [4] and Laser-Engineered Net Shaping (LENS) [5], Selective Laser Cladding [6], Controlled Metal Buildup (CMB) [7] and Shape Deposition Manufacturing (SDM) [8] have been developed. The feature common to all of these approaches is that metals supplied either in the form of powder or wire, are melted directly. Due to the complete melting, however, the accuracy and surface quality of the freeform fabricated parts are generally lower than those of machined parts.

A combination of additive and subtractive techniques offers a possible method to overcome this process-inherent problem. In the past, such an approach has been implemented in the Shape Deposition Manufacturing (SDM) process at Stanford University and in the Controlled Material Buildup (CMB) process developed at the IPT Aachen. In these processes, each layer is deposited as a near-net shape using the thermal deposition process, mainly laser cladding. The layer is then further shaped in a CNC milling operation to a net shape before the next layer is added. In SDM processes, the top as well as the side surfaces of each layer are machined and then protected by adding a copper support structure. This support structure is then removed with an etching process when the part is finished. Our group has developed a similar approach, 3D welding and milling, using gas metal arc welding instead of laser cladding to deposit single beads faster and more economically [9,10].

One of the unique capabilities of the powder-based laser deposition processes is the ability to perform a real-time adjustment to the mixture of the powder entering the molten pool and, thus, alter the deposited material’s composition [11]. This feature can enable designers to tailor localized material characteristics depending on the requirements of a specific application. For instance, it can allow building functionally graded material parts such as injection molds that have hard-tool steel in the outer region, where excessive wear is expected, and steel in the inside producing a better thermal conduction [12]. In this study, we investigated the degree to

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which this unique capability can be achieved with our wire-based 3D welding and milling process.

2. Development of deposition strategies

In the 3D welding and milling process, conventional gas metal arc welding is used to deposit single beads side by side. Depending on the welding parameters such as speed and power, the bead thickness varies between 0.5 and 1.5 mm. When a layer is deposited, its top surface is machined to obtain a smooth surface with a certain thickness for further deposition, as shown in Fig. 1. The combination of this process with face milling offers a distinct advantage in setting layer thicknesses between 0.1 and 1 mm. When the sequence of deposition and face milling is finished, surface finishing is applied in the same setup to remove the remaining stair steps on the surface and to increase the accuracy of the near-net shape metal part.

To build a multi-material part, we developed two different approaches. As shown in Fig. 2, the first approach is to set the number of welding guns to the number of materials to be deposited. The 3D welding and milling equipment is based on a conventional three-axis milling machine, as shown in Fig. 3, and it can easily be reconfigured to adopt this approach. In the current version, two welding guns are attached to the spindle,

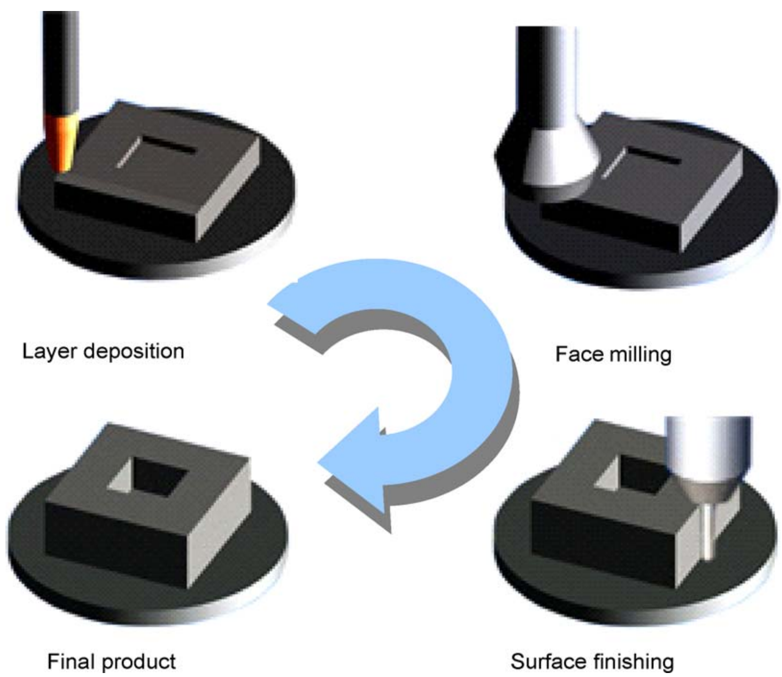

Fig. 1. Process principle of 3D welding and milling.

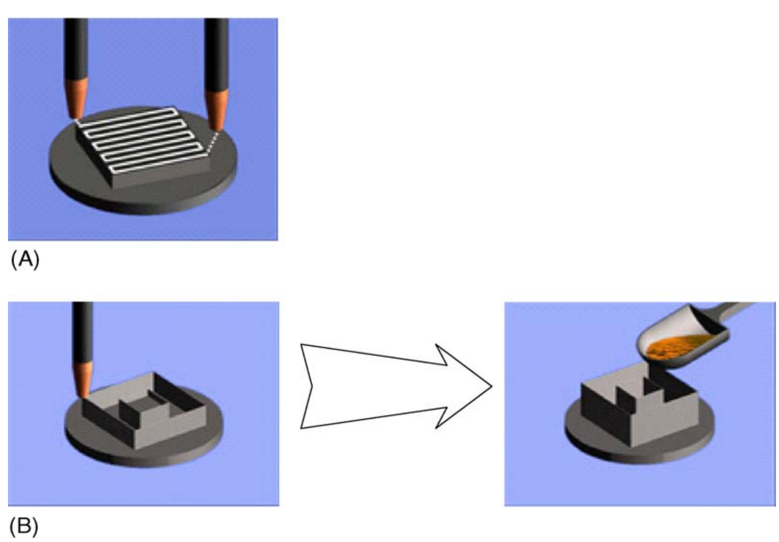

Fig. 2. Two different building strategies for bi-material parts: (A) deposition of two different materials and (B) deposition and subsequent filling of shell.