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A Thermal Spray Approach to Rapid Prototyping—An Extended Abstract*

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1. Introduction

TO SUCCESSFULLY compete in today's global markets requires rapid product development and manufacturing of bold new designs to respond to changing market demands. Success requires several innovative manufacturing activities. For one example, computer-aided design (CAD) and computer-aided manufacturing (CAM) systems are required that can quickly produce physical objects directly from CAD models with minimal human intervention. Such objects include prototypes, to facilitate the design process, and custom tooling, such as injection molds, for mass production. This abstract describes an emerging set of freeform fabrication processes, including several approaches based on thermal spray, that will facilitate rapid prototyping.

2. Conventional Fabrication Processes

Conventional CAM systems have relied mainly on computer numerically-controlled (CNC) machining to fabricate new shapes. Planning CNC operations, whether performed manually or using an automated approach, can be a difficult and time-consuming task. Planning requires the recognition of three-dimensional geometric features and understanding of their interactions as related to machining processes. Decisions must be made on the types of tooling and the sequence of operations required to build the parts. Part-specific fixturing, required to hold the parts while they are being machined, must also be selected and designed, and skilled machinists are required to operate the CNC machinery. The time required to manually plan and execute CNC operations is related directly to the geometric complexity of the part. While progress has been made toward automating this process, a significant amount of expert human interaction is still required; this remains a challenging research problem.

3. Solid Freeform Fabrication Processes

In contrast to the material removal processes associated with CNC machining, solid freeform fabrication processes build parts by incremental material buildup of thin planar layers. Each layer is fused to the previously deposited layer, and the growing structure may be supported by solid sacrificial layers, in complementary shapes, eliminating the need for custom fixturing. The cross-sectional descriptions are generated by "slicing" three-dimensional computer representations into "slices" that may vary in thickness (Ref 1). Several alternative materials and deposition processes are available for building the part, including stereolithography, selective laser sintering, three-dimensional printing, solid ground curing, fused deposition modeling, and recursive masking and deposition (Ref 2).

Key Words: net-shaping, rapid prototyping, recursively mask and deposit

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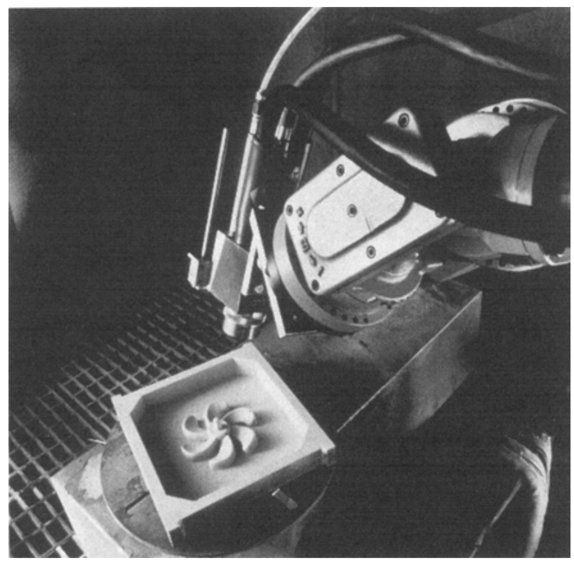
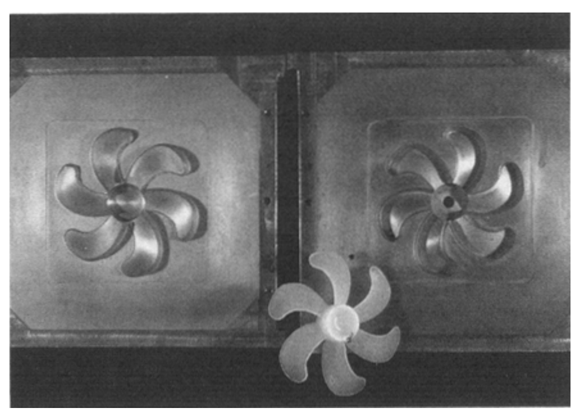


(a)



(b)

Fig. 1 Robot spraying zinc onto pattern built with stereolithography (a) quickly produces prototype injection mold tool (b)

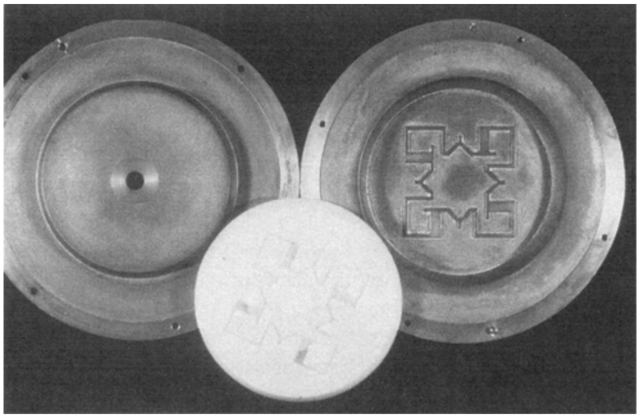


Fig. 2 Sprayed 410 stainless steel-faced injection mold

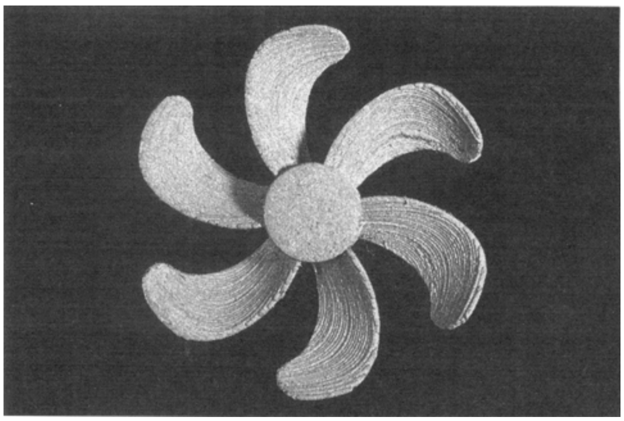


Fig. 3 Prototype propeller shape built with MD

A principal advantage of the freeform fabrication approach is the ease and speed with which one can go from part design to part fabrication within a completely automated CAD/CAM environment. In contrast to CNC machining, the freeform fabrication processes operate on simple planar geometries that do not require part-specific fixturing or tooling information. Since three-dimensional shapes are decomposed into two-dimensional layers, the planning and execution effort for freeform fabrication is essentially independent of the part's geometric complexity. Operating the freeform fabrication apparatus also requires minimal human intervention. The part designer can even personally operate this equipment.

Several freeform fabrication processes based on thermal spraying are being investigated at Carnegie Mellon University. In one application, a robot-manipulated arc sprayer (Fig. 1a) creates zinc-faced tooling (Fig. 1b) using patterns built with stereolithography (Ref 3). A process for building sprayed steel-faced tooling (Fig. 2) has also been developed (Ref 4). The use of robotic thermal spraying is also being investigated for building shapes directly in a layered fashion (Fig. 3). This approach, called MD, which signifies "to recursively mask and deposit," sprays each layer using a disposable mask that has the shape of the current cross section (Ref 5). Masks are produced from paper rolls with a CO_2 laser. Novel assemblies are also feasible since masking allows selective material deposition within each layer. Therefore, different components can be formed and embedded in a single structure. For example, the fabrication and assembly of completely encapsulated electronic-mechanical structures (Fig. 4) can be integrated into a single process (Ref 6).

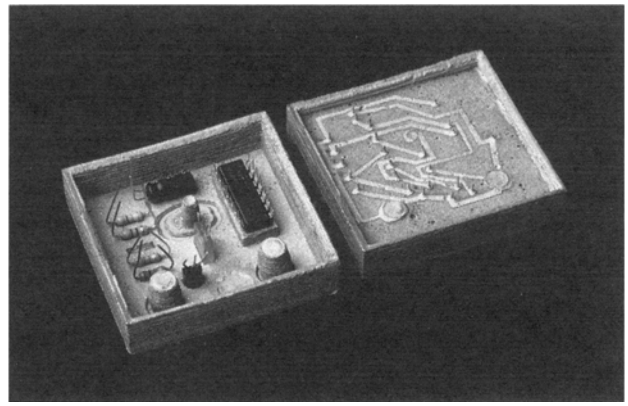


Fig. 4 Spray-formed electronics housing and interconnects built with MD

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