Virtual Simulation for Multi-material LM Process

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1. Abstract

In an ONR funded MURI program, to improve quality of multi-material parts, we've been developing an advanced computer simulation for the multi-material layered manufacturing (LM) process. The CAD models and their .stl files are created using the commercially available software such as I-DEAS and ProE. Using this information, one tool path file per material is generated. Our file preparation algorithm, systematically, layer by layer, integrates all tool path files into one multi-material tool path file. The results of the multi-material tool path are graphically visualized using the simulation algorithm (written in C++ & SGI OpenGL). From a virtual simulation, we can check the LM process, and make the best selection of tool path parameters afterwards. After several trials from design to simulation, if the simulation result is acceptable, the real manufacturing can be started. And the part's quality should be better than a part manufactured without running simulation in advance. This paper will represent new studies on using real roadshapes to get more realistic simulation results. Many parts have been successfully simulated using our method.

2. Background

Layered Manufacturing (LM) technologies have been developed rapidly in the past decade. LM has significant differences from traditional fabrication technologies. LM refers to the process of fabricating three dimensional objects from CAD-generated solid models layer by layer [1]. A computer generated model of a part usually contains surface information. It is imported into a slicing program which mathematically slices the model into sequential horizontal layers, and the hardware specific toolpath for each layer is created. This toolpath file then is downloaded into the LM hardware, which fabricates the model layer by layer, following the specified path. It is different from traditional manufacturing in the sense that the part is produced by adding materials rather than removing materials. Using this technology, parts with a single (non support) material have been fabricated. Currently, there are mainly single component material LM technologies available. A representative listm [2] includes: 3D System's Stereolithography Apparatus(SLA) series, Stratasys's Fused Deposition Modeling Process(FDM), Sanders, and 3D Printing. Although those LM technologies may have multiple material options before starting the manufacturing process, they can only handle one component material during one building process. They are not true multi-material LM process.

Multi-material LM refers to a process of fabricating a part consisting of more than one material from a three dimensional CAD model layer by layer. A multi-material

CAD model consists of several different material blocks connected by interface boundaries. The LM system under development should be able to generate CAD model, slicing file, toolpath file and fabricate a multi-material part in a manufacturing process. The development of our multi-material LM system is still at the research stage. On the software development side, the CAD/CAM group at the university of Michigan has been investigating multi-material LM issues [3]. They are developing an integrated software system for LM process planning, which includes solid model building, part orientation, support structure generation, slicing, and path planning for multi-material solid models. In a Solid Model Builder module, the multi-material object will be represented by gray scale images, where a particular gray value is assigned to each individual material or it may also indicate material property such as density. There are several multi-material LM technologies under development currently. In Sandia National Laboratories, Robocasting technology, a freeform fabrication technique for dense ceramics and composites that is based on layer-wise deposition of highly load colloidal slurries, is being developed [7]. Mold Shape Deposition Manufacturing technology in Stanford University is a Solid Freeform Fabrication technique for producing complex fugitive wax molds which can fabricate multi-material parts [8].

3. Objective

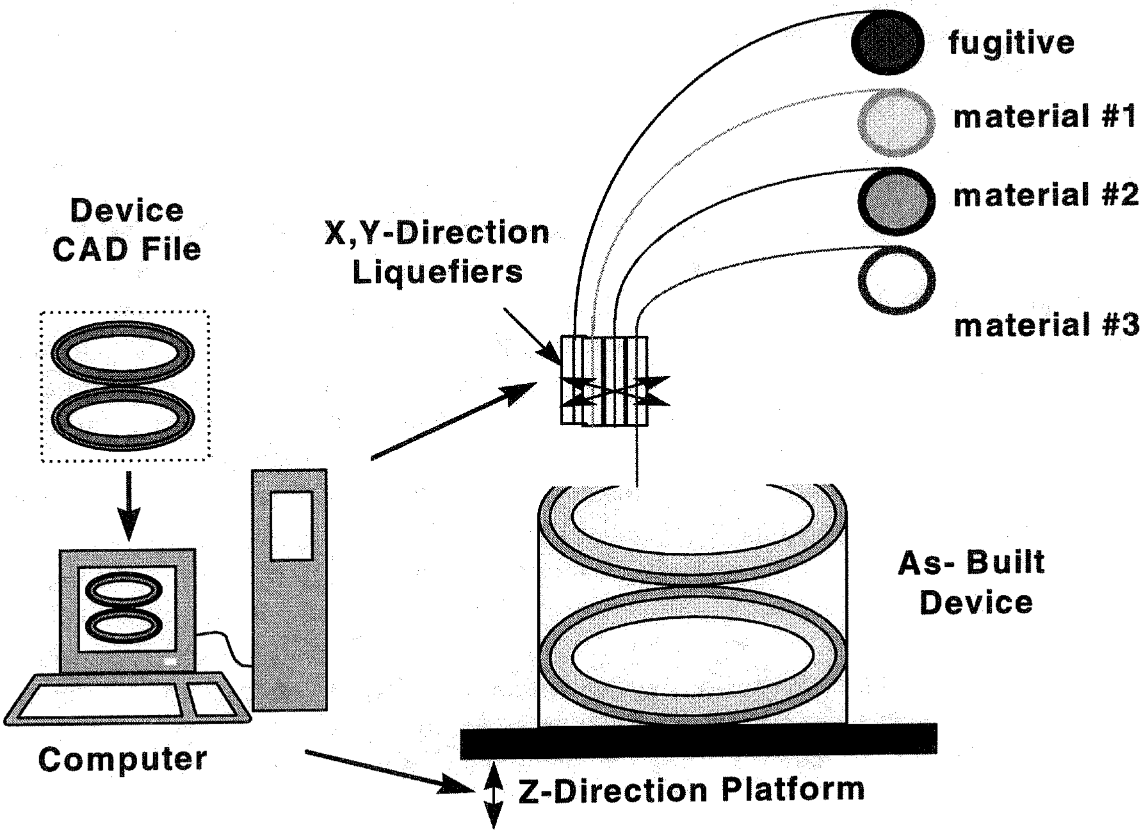


Fig 1 MURI multi-material LM system

Currently, at Rutgers University, under an ONR(Office of Navy Research) funded MURI program[4], An Intelligent Layered Manufacturing (LM) system (Fig 1) for fabrication of multiphase electromechanical parts has been developed. This program will requires development of design and construction of an intelligent multi-material LM system, processing science for multi-material LM, CAD based design and manufacture of multi-phase electromechanical components. The intelligent multi-material LM system should include a high quality multi-material layered manufacturing machine (hardware), and a CAD based intelligent multi-material LM software system. In the recent past, the MURI hardware as well as corresponding software has been developed and several parts have been successfully fabricated.

To achieve the development of a multi-material LM software system, one of the necessary requirements is to perform the virtual simulation of the multi-material LM process. This paper discusses the implementation of the virtual LM simulation and it's results. The objective of this study is to develop an advanced computer simulation for the multi-material LM process. In the present program, quality of a part is considered to be very important. We use the simulation to understand, and check the LM process before the real manufacturing. It is one of the steps to improve parts' quality. With computer simulation, it's possible to go through multiple design-simulation iterations within a short time, which can substantially improve the LM part quality.

4. Method

The simulation package under development includes two main portions. The first one is a file preparation algorithm to generate the single multi-material toolpath file from multiple CAD solid models. The second one is the graphical simulation algorithm. The schematic flow and the simulation software development has been described in [5].

4.1. File preparation

To perform a realistic simulation of a multi-material part fabrication, a multi-material toolpath file is required. The simulation process starts from a CAD model. Commercially available software such as I-DEAS or Pro-E can be used to create CAD models which represent different materials in a multi-material model. For each material a separate .stl file is created, while keeping its space location. These .stl files are then sliced and a toolpath is generated individually for each of them. Currently, we use QuickSlice software to create one toolpath file per material. This information is then used as the input to an in house file merge algorithm, which systematically, layer by layer, integrates all tool path build files into one multi-material toolpath build file.

4.2. Graphical simulation algorithm

The simulation package includes an in house graphical simulation algorithm (written in C++ and OpenGL). The algorithm extracts critical information from a multi-material toolpath build file, and utilizes SGI OpenGL to run the simulation, as it provides necessary graphical tools: coloring & shading, solid modeling, 3D viewing, and animation tools. The simulation opens a graphical window, specifies a color set for all materials, and starts the "material deposition" process along the tool path on the starting layer. When one material is finished, the simulation runs the "material deposition" process for other materials on the same layer. When one layer is finished, a new layer will be "deposited" on top of the finished layer, until all the layers of the part are stacked sequentially. That's the graphical stacking process for multi-material parts, which simulates the physical multi-material LM process.

The shape and size of the deposited road in LM process using a nozzle is different from the nozzle cross sectional shape and size. This is due to the flow properties of the material as well as the shearing action of that translating nozzle. Considering a circular cross sectional nozzle, with a low viscosity and high surface tension material as wax, the road shape will remain close to a sphere. Where as, with high viscosity and low surface tension material such as ceramic or metal powder filled polymer, the road shape will be flatter. In addition, the shear action of the nozzle, and the adjacent road will alter the shape of the road. This implies that the virtual simulation should account for different road shapes for different materials. The current simulation have spherical roadshape as well as roadshapes obtained experimentally with specific toolpath parameters .

5. Previous Study

Several critical parameters for a build file were investigated [5]. They include roadwidth, offset (air gap between parallel roads), layer thickness, and raster angle. These parameters have different sensitivities in void creation or elimination. An idealized roadshape of sphere was considered. The relationships between parameters and void size have been studied, results can be summarized as follows:

1. Roadwidth is a sensitive parameter for sub-perimeter void size. However, the voids' sizes don't necessarily decrease when roadwidth decreases. The sub-perimeter void size depends on if the width in the perpendicular direction to the vector direction can be divided equally by the roadwidth.
2. Sub-parameter void size is directly related to boundary offset values. Similarly, vector road void size is directly related to vector offset size, But the vector angle has no apparent relationship with void size.
3. Slice thickness is not a sensitive parameter. But if the slice thickness is too big, there will be voids between layers.

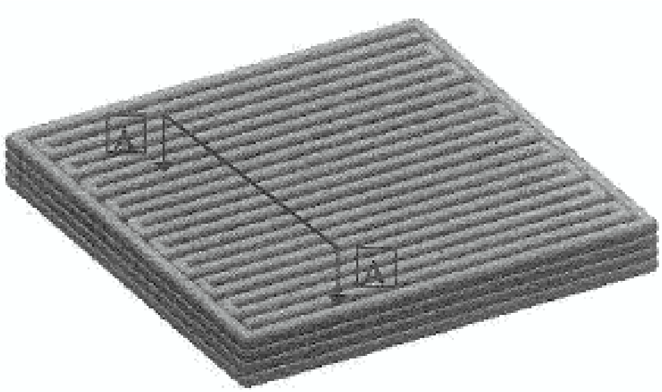
In a parallel study, video microscopy [6] of the deposited road was performed. This information is utilized on the same experimental part to understand void & defect creation or elimination.

6. Simulation using Physical Roadshape

The above parametric study was on a spherical or idealized roadshape. To check a specified LM process in advance, a realistic way is to run the simulation using the actual roadshape, thus the simulation result will be more accurate, and the quantification of voids will be more meaningful. The virtual simulation will be run before each fabrication to make adjustments in advance. The adjustments based on that result will also improve part's quality.

On the other hand, we use video microscopy to observe the real roadshape for a parameter-specified LM process [6]. The video microscopy uses CCD camera to capture the real time images of the experimental LM process. The actual roadshape can be identified from those images. HLImage++ 97 has been utilized to quantify the void information.

To have a good understanding of the effect that toolpath parameters have on quality of the LM parts, a simple rectangular part (Fig 2) has been considered. The result on the idealized spherical roadshape [5] is shown here for comparison with real roadshape. The video microscopy data on PZT (Fig 3) were quantified and used in the simulation. The results of the deposited road at section A-A (Fig 2) for -4, 0, +4 mil offset were developed. Both the spherical roadshape and truncated ellipsoidal roads were used.



Specifications:	Roadwidth: 20 mil	Nozzel size: 15 mil
	Offset: +4, 0, -4 mil	Slice thickness: 10 mil
	Material: PZT	

Fig 2: A rectangular part with 0 degree Vector Angle

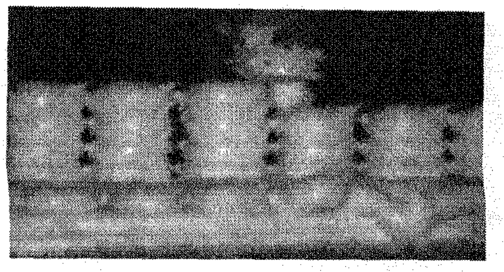
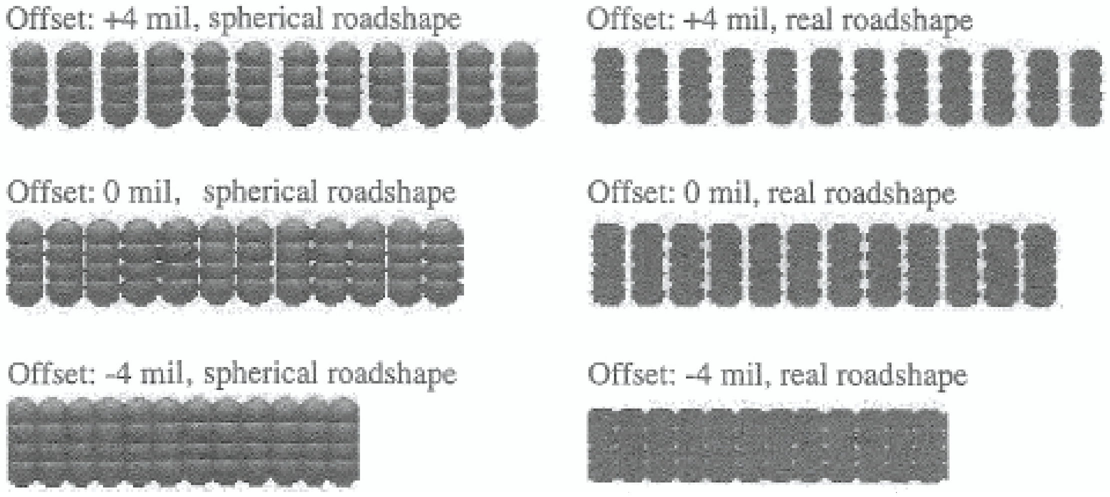


Fig 3 : Videomicroscopy image of a PZT rectangular part of Fig 2 (offset: 0 mil)



Offset: +4 mil, spherical roadshape

Offset: +4 mil, real roadshape

Offset: 0 mil, spherical roadshape

Offset: 0 mil, real roadshape

Offset: -4 mil, spherical roadshape

Offset: -4 mil, real roadshape

Fig 4: A-A cross section simulation images of this part.

The images of twelve deposited roads for each vector offset and each roadshape in the simulation are shown graphically (Fig 4). As the offset size changes from +4 mil to -4 mil, the width of twelve deposited roads reduces significantly. The deposited part is more dense.

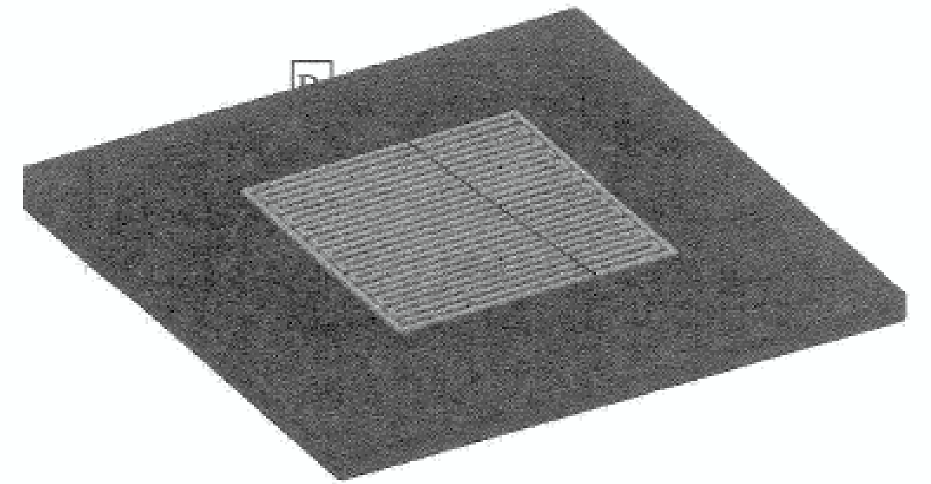
In the actual building experiment (Fig 3), to capture the voids between roads, the boundary was not build. The returns of the roads were kept, that's why the roadwidth in the video microscopy picture appears double size of the simulation roadwidth except at the nozzle tip(Fig 3).

As can be seen from the above images, the void shape and size for different roadshape are different. Using HLImage++97 software, we quantified the void size. For 0 mil offset, the average void area in the video microscopy image (Fig 3) is 40 mil^2. The average void area from the corresponding simulation image (Fig 4, offset: 0 mil) using spherical roadshape is 15 mil^2, and for real roadshape is 36 mil^2 (Fig 4). The simulation result using physical roadshape is closer to the real part's result.

7. Simulation of a two-material part

One of the desired goals of simulation software is to understand the interaction of materials in the LM process. The video microscopy will provide the needed data on the roadshape for each material. Utilizing that information, specifying roadshape specific to each material, will result in a more accurate simulation of multi-material parts.

A two material part was designed and simulated (Fig5). This part consists of two materials: PZT and fugitive wax phase. From a video microscopy experiment with the specifications, we captured the roadshapes for those two materials. The road shape for PZT is flatter and the roadshape for wax is almost spherical (Fig 6).



Specifications:

Roadwidth: 20 mil
Slice thickness: 10 mil
Offset (for PZT): -4 mil
Nozzel size: 15 mil
Offset (for wax): -4 mil

Fig 5 : A two material part (Wax: 1" x 1", PZT: 0.5" x 0.5")

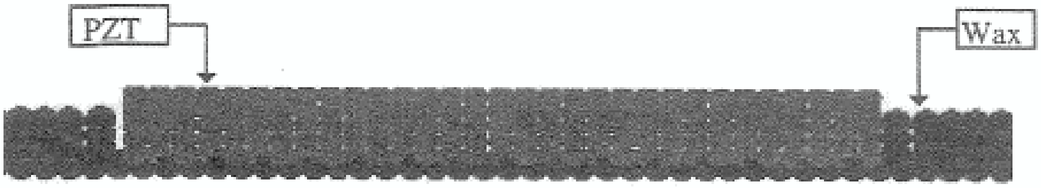


Fig 6 : The B-B cross section view of Fig 5 (amplified)

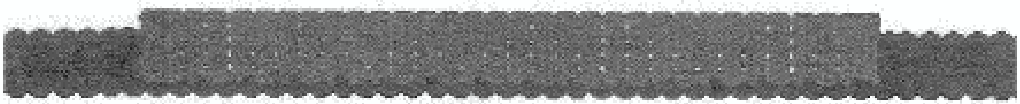


Fig 7 : Same view as Fig 6 with different offset for wax

The simulation of PZT-wax part demonstrate the potential applicability of the system (Figures 6 and 7). With -4 mil offset, each material in this part is almost void free. But when the interface offset between two adjacent materials is 0 mil, the interface void existed (Figure 6). Whereas the interface void vanished (Figure 7) when the interface offset changed to -4 mil. This experiment shows that in multi-material LM, not only the offset in each material, but also the interface offset between every two adjacent materials should be investigated.

As more information on the road shapes and the material interaction become available, the current simulation will become more intelligent.

8. Conclusion

A Multi-material Virtual Simulation System has been developed for LM. A variety of parts with interconnectivity have been simulated using roadshape information from videomicroscopy experiments. This study demonstrates that multi-material layered manufacturing simulationss can provide accurate and detailed information. Based on this information, we can make selections of part's parameters and make adjustments to the fabricating environment to get high quality parts.

9. Acknowledgments

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10. References

1. M. Agarwala, A. Bandyopadhyay, R. van Weeren, V. Jamalabad, P. Whalen, N. A. Langrana, A. Safari,, S. C. Danforth, "Fused Deposition of Ceramics", J. Rapid Prototyping, Vol. 2, 4, pp. 4-19, (1996).
2. X. Yan, P. Gu, "A Review of Rapid Prototyping Technologies and Systems", Computer-Aided Design, Vol. 28, No. 4, pp. 307-318, 1996.
3. A. L. Marsan, S. Allen, P. Kulkarni, and D. Dutta, "An Integrated Software System for Process Planning for layered Manufacturing", Proceedings of the Solid Freeform Fabrication Symposium, pp. 661-668, The University of Texas at Austin, Austin, TX, August 1997.
4. Office of Naval Research (ONR), # N00014-96-1-1175 Multidisciplinary Research Program of the Univ. Research Initiative (MURI): An Intelligent CAD Based System.
5. D. Qiu, N. Langrana, S. C. Danforth, A. Safari, M. Jafari, "Development of Multi-material Virtual Layered Manufacturing Simulation", the Proceedings of Third Pacific Rim International Conference on Advanced Materials and Processing, Hawaii, July, 1998.
6. E. Bossett, McCuiston, N. Langrana, Rangarajan, Venkataraman, S. C. Danforth, A. Safari, "Real Time Video Mcroscopy for the Fused Deposition Method", to be presented at the Ninth Solid Freeform Fabrication Symposium, August, 1998.
7. J. Cesarano III, B. King, H. Denham, "Recent Developments in Robocasting of Ceramics and Multi-material Deposition", to be presented at the Ninth Solid Freeform Fabrication Symposium, August, 1998.
8. A. Cooper, S. Kang, J. Kietzman, Fritz, "Automated Fabrication of Complex Molded Parts Using Mold SDM", to be presented at the Ninth Solid Freeform Fabrication Symposium, August, 1998.