Rapid Prototyping by Injection Molding

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Abstract

Thick layered rapid manufacturing, using injection molding techniques, integrates the concept of layered manufacturing into the molding process. This process takes an STL file of a part and decomposes it into layers that can be milled on a 3-axis machine. New STL files are then created of each layer, where upon these layers are used to create mold cavities. Machining code is then written for each mold, and the mold is cut using the 3-axis mill. The layers of the part are then molded and combined to form the whole part. In this way, complex parts can be molded without concern for injection molding flaws in the part or complicated mold design. This technique allows the production of thousands of complex parts directly from a CAD file in a few days.

Introduction

The goal of Rapid Prototyping by Injection Molding (RPIM) is to produce a medium to large quantity of prototypes/parts directly from a CAD file in s short time. In addition, the process should be relatively unskilled and automatic. The techniques used in RPIM, layered manufacturing, NC machining, and injection molding, are common techniques that have been around for a number of years. Each of them have their advantages and disadvantages, and this process is intended to combine the advantages from these techniques while minimizing the disadvantages.

Layered Manufacturing

Most rapid prototyping systems currently available employ an additive process for the prototype construction (Thomas, 1995). This means that the part in question is decomposed into layers, and each individual layer is constructed and "stacked" upon the previous layer, hence, an additive process. This process is also known as layered manufacturing or solid freeform fabrication (Deckard, 1987). The advantage of creating parts in layers and then stacking them is that the complexity of the manufacturing process is greatly reduced. One only needs to know the contour of any specific layer to create that layer. As a result, this process can produce almost any geometry.

One disadvantage of a process such as this is that it is not as accurate as one might wish. An example of the tolerances available with this type of process would be from 8 to12 thousands of an inch for a Stratasys® FDM1650 fused deposition modeling machine (Stratasys®, 1996). The available surface finish for this process is also relatively poor. This process is also quite fast at producing an individual part, but very slow in terms of mass production.

Numerical Controlled Machining

One might also consider another type of rapid prototyping to be a subtractive method such as NC machining. In NC machining, the part is simply "cut" out of an existing block of material; unwanted material is removed form the block to reveal the part. This process is extremely accurate in its tolerances and provides an excellent surface finish. For example, the repeatable tolerance on a Bridgeport® Discovery Torq-Cut 22 Vertical CNC machine is ± 0.00015 inches (Bridgeport®, 1995).

The disadvantages to this technique are that it requires a skilled operator to run the machine, with extensive planning and design in the manufacturing process, and it also requires a wide range of tooling to produce a wide range of parts. Another disadvantage, perhaps the biggest, is that some geometries are very difficult to produce or even impossible. For example, a cavity in the middle of the part would be impossible since there is no way to get to it to remove the material.

Injection Molding

The next technique used in this process is injection molding. Injection molding is a process through which a mold is created, where upon the mold is injected with a heated polymer to produce the part. This technique is a very fast and efficient means for producing many, identical parts.

A disadvantage to this process is that the mold design can be very complicated and expensive. Injection molding also limits the geometry that can be manufactured. For example, thick walled parts are difficult or impossible to mold.

RPIM Concept

Previous researchers have developed prototyping techniques based on the decomposition of complex 3D parts into thick layers. L.E. Weiss and F. B. Prinz developed an automated manufacturing process known as Shape Deposition Manufacturing, or SDM (Weiss, 1998). SDM combines the concepts of molten metal droplet deposition and CNC machining to produce 3D, complex-shaped, multi-material structures. F. Zafar Shaikh and coworkers developed a manual process known as Precision Stratiform® Machining, which decomposes a complex, 3D part into layers that can be machined with an NC machine (Shaikh, 1997). The Stratiform® process then combines the machined layers using a vacuum furnace brazing process that creates leak free, brazed joints between the connecting layers. Cheol H. Lee developed a method known as Ruled Thick Layered Rapid Prototyping, which incorporates ruled edges on the layer decomposition to build large, 3D, complex geometries (Chamberlain, 1998).

RPIM begins with an automated adaptation of the Stratiform® process, except that it machines molds of the thick layers. The end product of RPIM is a collection of thick injection molded slices instead of a unitary part as with SDM. The concept of RPIM takes the techniques of layered manufacturing, NC machining, and injection molding and combines these three processes into a single new process. The following steps outline the operation of RPIM:

- Decomposition of a general 3D CAD object into 3 axis machinable layers
- Generation of 2 part mold surfaces from layers
- Generation of interlocking features to lock adjoining layers
- Generation of tool paths to machine mold cavities
- Machining of the cavities into standard mold inserts
- Molding of the layers
- Assembly of molded layers

Decomposition of general 3D CAD object into 3 axis machinable layers

The first thing that must be accomplished is to decompose the part into layers that are machinable by a 3-axis NC machine. In order to accomplish this, the part must be split at intersections where, in the splitting plane, downward facing surfaces meet upward facing surfaces. In this way all layer surfaces will be seen either from a top view or from a bottom view, allowing the surfaces to be machined with a 3-axis NC machine. This will also allow for a two-part mold.

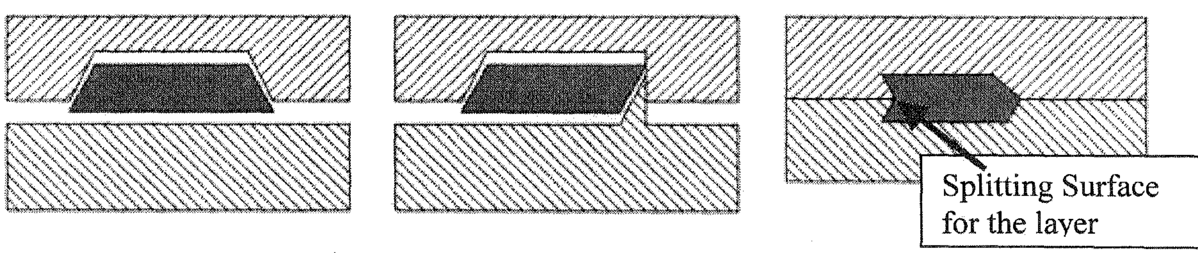

Figure 1
Parting Surface Between Layers

Another consideration to take into account when decomposing each layer is to be aware that a single layer thickness must not exceed approximately 0.125 inches. This is the approximate maximum thickness at which any part should be molded do to shrinkage/sinking. Sinking occurs when the part is removed from the mold and begins to cool. If the part is too thick, the internal stresses created by the cooling process will pull the outer walls inward creating a "sink" in the part (Dym, 1987).

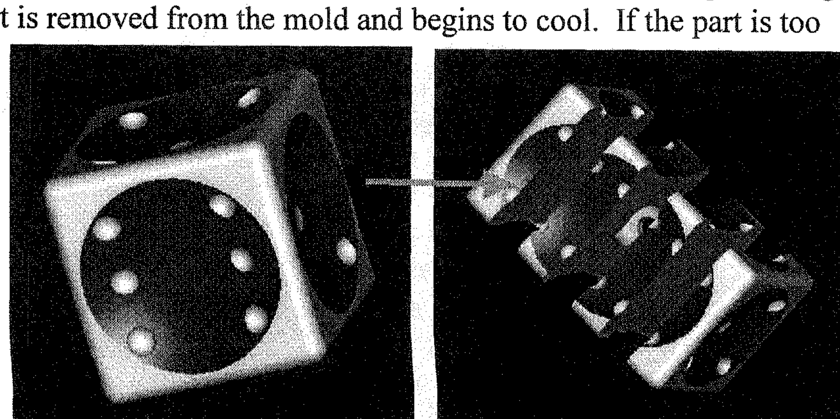

Figure 2
Example of Thick Part Decomposition

Figure 2 shows an example of a die that is very difficult to injection mold. This die has concave surfaces on all six sides with further concave indentations to represent the number markings on each side. This die also contains a cavity within the core. All of these factors make this die difficult, or even impossible to injection mold. It is therefore split into layers along horizontal planes where downward facing surfaces meet upward facing surfaces. This occurs in the middle of each concave indentation.

Generation of 2 part mold surface from layers

The next phase of the process is to place the layers within a mold, creating a two-half mold to inject the layers. During this phase of the process, consideration must be given for injection molding constraints. A standard mold insert will be used for the injection process, limiting the number of layers that will fit into any one mold. Allowances must also be made to fit runners within the mold, which are channels for the heated polymer to reach the part layers. Ejector pin placement is also a factor when placing the layers in the mold. The layers must be ejected from the mold with the ejector pins. This reduces the possibility of the part sticking in the mold cavity. A final consideration is for vertical edges in the mold. If the layers have vertical surfaces in the mold relative to the mold face, draft angles will have to be implemented on those surfaces to facilitate the ejection of the part layer. Figure 3 show the example of the die layers within the standard mold inserts.

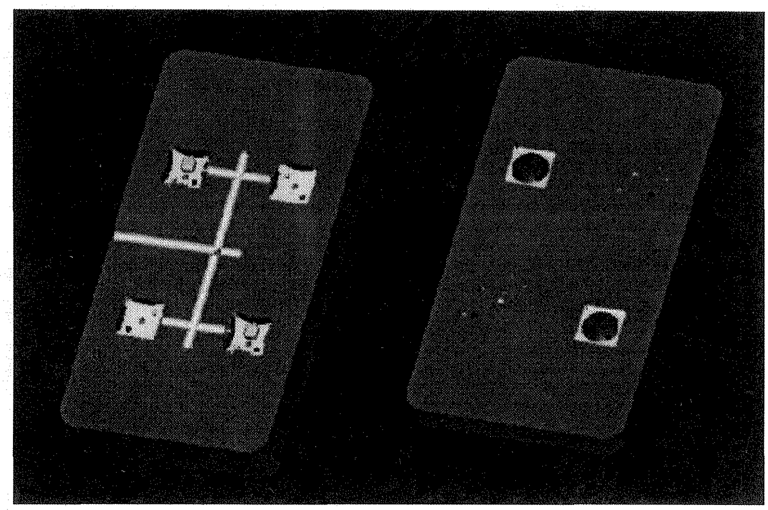

Figure 3
Mold Halves for Die Example

Generation of Interlocking Features to Lock Adjoining Layers

Interlocking features are necessary to reference one layer with another. This can be accomplished in several different ways. One way is to create a small hemisphere that protrudes from the surface of one layer, and then to create a matching cavity of the hemisphere on the adjoining layer. When the layers are brought together, the hemisphere from the first layer will go into the cavity on the second layer referencing the two layers together. Figure 4 shows how this may be accomplished.

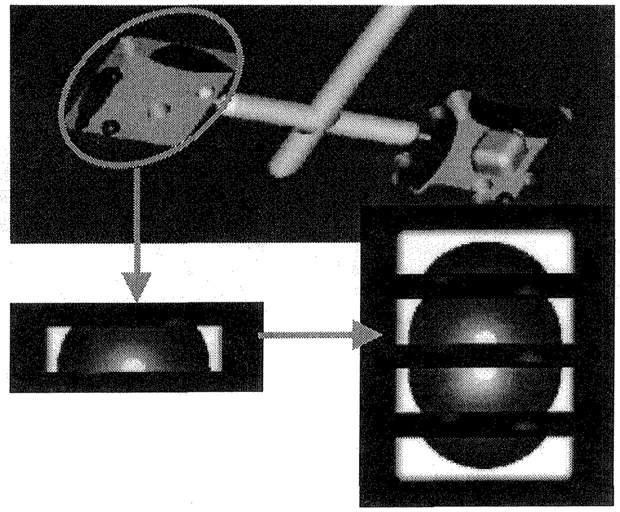

Figure 4
Example of Interlocking Features to Position Adjoining Layers

Another possibility would be to use the ejector pins to create the locking features. This could be accomplished by making the ejector pins a little too long for one layer, thereby creating a cavity on that layer; and making the ejector pins a little too short on the adjoining layer, creating a small protrusion. However, in order for the layers to be positioned correctly with respect to each other, the pins would have to be positioned in such a manner as to be at the same place on each adjoining surface. Figure 5 shows the interlocking features created by the ejector pins on another example part.

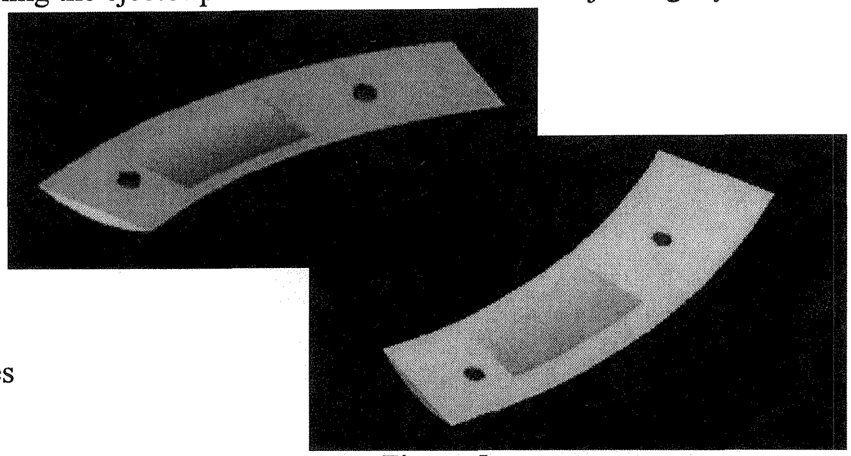

Figure 5
Interlocking Features Created Using the Ejector Pins

Generation of Tool Paths to Machine Mold Cavities

After the layers are inlayed into the mold halves and the interlocking features have been created, tool paths are then generated. Tool paths are the code that tells a certain CNC machine how to move the cutting tools to create the part that has been designed. Different codes exist for different machines. Therefore, the determination of what code is to be implemented will depend on the machine that will be used for the cutting process. The tool paths, in this case, will tell the NC machine to cut the cavities for the each part layer that has been created.

Machining of the cavities into standard mold inserts

The machining of the cavities will be done on a 3-axis mill. This means that the cutting tool of the mill will only be able to move in three planes of motion: left-right, forward-backward, and up-down. Each layer of the part has been generated so that their cavities will be machinable with this type of NC machine, reducing the complexity of the machining process. Figure 6 shows a simulation of a die cavity being machined. As can be seen in the figure, the cutting tool can reach each point on the surface of the cavity by moving in the three planes of motion.

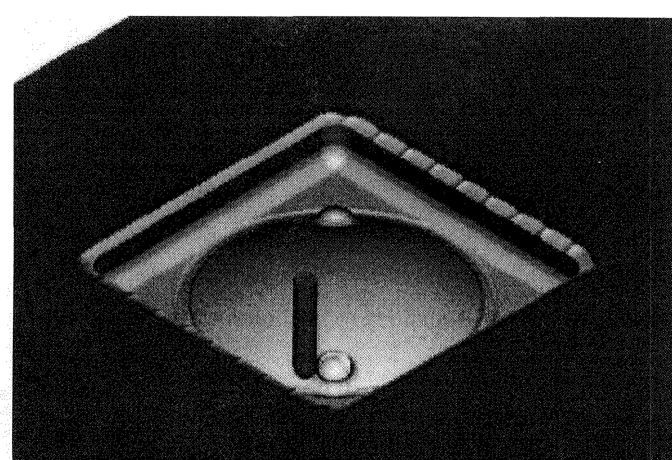

Figure 6
Simulation of NC Machining of Mold Cavities

Molding and Stacking the layers

The next phase in the process is to mold the individual layers on a standard injection molding machine. Once each layer has been molded, it can then be stacked and bonded together with the other layers to form the entire part. The interlocking features will align each layer to the adjoining layer, referencing the entire part together.

Conclusion

Rapid Prototyping by Injection Molding uses the best features of layered manufacturing, NC machining, and injection molding to produce a medium to large quantity of prototypes/parts. With layered manufacturing, one can produce almost any geometry imaginable, including overhanging dimensions and cavities. This process also significantly reduces the complexity of the entire part by decomposing it into several layers, each of which are simple to construct. NC machining, which is very accurate in its dimensioning and surface finish, is used in the mold construction; and since the design of the mold has been simplified by the decomposition process, an expert machinist will not have to be employed to operate the NC machine. Injection molding is the final technique used which is the perfect process for producing a large quantity of the same part. Therefore, Rapid Prototyping by Injection Molding is the perfect process for creating a medium to large quantity of prototypes/parts.

Future Work

Future work for this process will be its automation. At present, software is being constructed that will take an STL file of a part, and automatically decompose it into the necessary layers for the process. It will then generate new STL files for each individual layer. Additional software will be created to take these new layer files and inlay them into a mold with the necessary locking features, ejector pin locations, and runners for the mold halves. It will then take these mold halves and generate the tool paths for the NC machine. Additional work can be done to index the layers, once molded, to stack them automatically.

References

Bridgeport®, *Installation & Maintenance Manual*, Discovery Torq-Cut 22 with Bridgeport DX-32 Control, Bed-Type Vertical Machining Center with Power Drawbar and Automatic Toolchanger, Bridgeport Machines, Inc., 1995.

Chamberlain, Peter, Van Roosendaal, Mark, Thomas, Charles, "Variable Thickness ruled edge slice generation and three-dimensional graphical error visualization," *Solid Freeform Fabrication Symposium Proceedings*, 1998.

Deckard, C. R., Beaman, J. J., "Solid Freeform Fabrication and Selective Powder Sintering," *15th North American Manufacturing Research Conference Proceedings*, Volume 2, SME, May 1987.

Dym, Joseph B., *Injection Molds and Molding*, A Practical Manual, Second Edition, Van Nostrand Reinhold Company Inc., New York, New York, 1987.

Shaikh, F. Zafar, et. al.," Precision Stratiform® Machining - 100 Day engine project", *Prototyping International*, 1997.

Thomas, C. L., *An Introduction to Rapid Prototyping*, Schroff Development Corp., Mission, Kansas, 1995

Weiss, L. E., Prinz, F. B. and coworkers, *Journal of Manufacturing Science and Engineering*, Transactions of the ASME v 120 n 3, ASME Fairfield, New Jersey, August, 1998.