

WirePATH: A New Method for Direct Rapid Tooling

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ABSTRACT

Shortening the lead-time for introducing a new product to the market has always been important to maximize profits and competitiveness. Recent developments in Computer Aided Design (CAD) technologies have significantly reduced the overall design cycle. However, the manufacturing process of the production mold still relies on slow and expensive machining processes. In this paper wirePATH, a new method to reduce manufacturing time for molds, patterns and dies, is presented. Using specialized interactive segmentation computer software and wire electrical discharge machining (wire-EDM), mold production time can be significantly reduced. When wirePATH is compared to other conventional methods such as milling, reduction in mold fabrication times can be as much as 40 to 70%. In addition, the method does not require special purpose equipment. We examine the details of the wirePATH process, describe when it can yield benefits, and compare the results to conventional methods.

INTRODUCTION

The plastic injection molding industry is estimated at \$20 billion per year and the current tool and die related industry is estimated to have annual revenue of about \$10 billion dollars [5]. Industry is pressured to reduce the time and the cost of product development while maintaining high quality. Faster product development often means getting to the market faster, enabling a stronger market position with premium pricing and higher profitability. In many industries, rapid product development is now a key aspect of competitive success.

All parts made with injection molding process need molds. The design and manufacture of mold consumes a significant portion of the lead-time for new product manufacturing. Six months and \$250,000 is not uncommon for a large highly detailed mold [5]. To speed up and reduce iterations of mold design and manufacturing, many industrial firms have employed mold analysis and CAD/CAM packages. However, the conventional method of constructing a mold still requires a significant amount of time for machining, sinker EDM process and labor intensive polishing. There have been many different approaches developed to speed up this mold making process [1-3, 5-10]. Some have been commercialized and others are still under development. Direct AIM, Copper Polyamide SLS, Direct Metal Laser Sintering, high-speed CNC aluminum tooling and PolySteel are some of the commercialized technologies [11]. They all have some limitations such as low production rate, limited cavity size and production volume. Typical molds are made with hard materials to resist wear for a longer tool life. When the molds are made with softer materials, as with many of these rapid tooling methods, they do not last long. Therefore, these rapid tooling methods are not applicable for parts that require high production quantity. When the molds are made with composites, the cycle time is much longer due to its poor thermal conductivity and the production rate will be lowered significantly. Our patented WirePATH technology is capable of producing metallic molds that can accommodate a wide range of applications including low production volume sand casting and investment casting as well as high production volume injection molding.

WIREFPATH TECHNOLOGY

WirePATH technology makes use of CAD, geometric modeling and wire EDM as its core components. Wire EDM is a process where a slowly and precisely controlled moving electrically charged wire travels along a prescribed path to cut conductive work piece with discharging sparks. Figure 1 shows the

illustration of wire EDM process. The top and bottom nozzle of wire EDM works as a guide and they can move independently to create various taper-angles and faces that are not vertical. Initial machining with high spark-energy settings can provide rough cuts. At this point, flushing pressures must be high—up to 300 psi. Skim cuts will remove a smaller amount of material typically from 0.0002 to 0.002 inches and allow for lower flushing pressures. With a lower flushing pressure and a high wire tension, the wire is not deflected. This results in greater cutting accuracy. Improved tolerance and optimal finishing are achieved by adjusting the spark energy downward to provide slower cutting speeds, and a smoother surface finish. The key advantages of wire EDM are that it is extremely accurate and can cut hard materials. It is ideal for material with hardness above RC 38. There is no contact between the wire and the work piece. Because the process does not involve force, contact or deformation, a wire EDM is capable of making walls as thin as 0.005 inches.

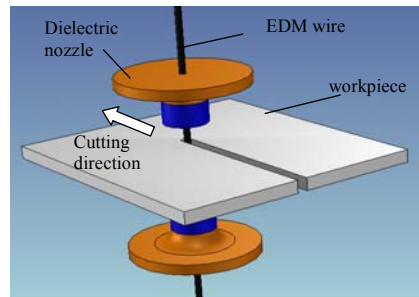


Figure 1: Workpiece is cut using electrically charged wire.

Wire EDM is currently being used mainly for producing protruded shapes such as punches and dies. Wire EDM applications in the mold-making industry have been limited to hole making and mold repairing. Our research enables new applications of wire EDM to more complex shapes by bridging the gap between CAD, our method, wire EDM and manufacturing processes. With the help of CAD technology, we show that complex molds can be made simple by decomposing it into smaller sections. We divide the complex geometry into sections and they are made with wire EDM or other manufacturing methods. Then all pieces are assembled to form a complete mold.

1. Different segmentation methods.

(1) WirePATH has two modes of segmentation. First mode is to segment mold into 3D segments. Appropriate level of segmentation depends on the type of mold and more importantly the geometry of the part. One extreme end is to segment the entire mold so that all pieces can be made with wire EDM. This approach is suitable for parts that are mostly prismatic. Figure 2. shows one of the insert molds that was designed and made for injection molding process. This mold was made using only wire EDM process.



Figure 2: From right- 2a:CAD model of the mold, 2b:all pieces of this insert mold were made with wireEDM, 2c:insert mold mounted in the injection molding machine.

Another variation of this method is to use combination of wire EDM and conventional machining. Complex freeform geometry can be made using machining and other areas, especially deep and narrow cavities, can be segmented using wire EDM. As shown in figure 3, by segmenting along the narrow cavity, hard to reach areas are now easily accessible. Therefore machining and polishing becomes much easier. Finishing and polishing are very labor intensive and they can take as much as 30% of the total mold manufacturing time [4]. Fine surface finish for injection mold is very important for easy part release and dimensional accuracy. As much as 90% of the machining time is spent on the secondary finishing work for some specialized molds. A typical wire EDM can give a smooth surface finish with multiple passes (up to $0.1 \mu\text{m Ra}$), and labor intensive polishing can be reduced.

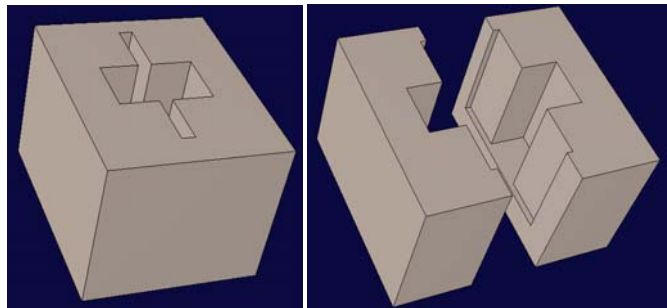


Figure 3: deep cavities can be access easier when made in two pieces.

There are other economical advantages in maintenance and repair as well. Also, it is easier to make changes to the mold. The completed mold can be changed to accommodate different product design changes by changing a section of the mold. When parts of the mold wears out or is damaged, that portion of the mold can be replaced, instead of making the entire mold again.

(2) The second mode of wirePATH is to use variable thickness adaptive layering. A mold is segmented using series of layers as in layer object manufacturing (LOM). What is unique about our layering approach is that the thickness of each layer is calculated so that it only uses available standard stocks to minimize preparation time and use variable taper angle in order to minimize error caused by stepping effect of LOM process. Figure 4 shows how a curved surface can be approximated by layers with variable thickness and variable tapered angles. For a given depth h , the curvature different thickness layers are used ($d_1, d_2, d_3, \dots, d_5$). These thicknesses are calculated and selected to match one of the standard plate thickness available.

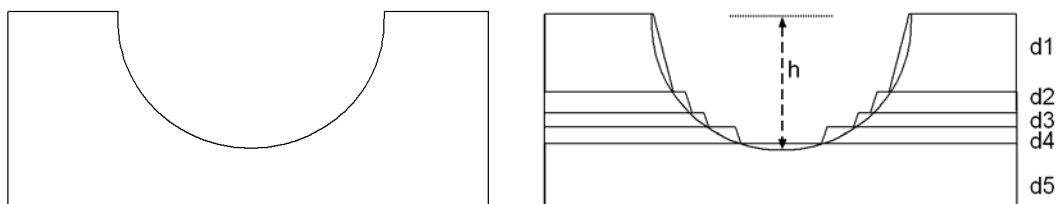


Figure 4: Adaptive slicing method with variable thickness and variable taper angle.

In a typical wire EDM, taper angle of 15° or higher will require special setup because of the poor flushing condition. Therefore it is necessary to layer parts so that it does not require cuts with more than 15° of taper angle. Once all the layers have been manufactured, they can be assembled and finished by using sinker EDM or CNC milling machine to achieve desired surface finish. For some casting applications where surface quality is not very critical, the finishing machining may not be necessary. Figure 5 shows

two molds that are made with layer mode of wirePATH. The first mold shown on the left is for injection molding and it was made without adaptive slicing. All layers are same thickness and there is no taper angle. The mold on the right is sand casting pattern for a core. It was made using standard thickness plate and variable taper angle.

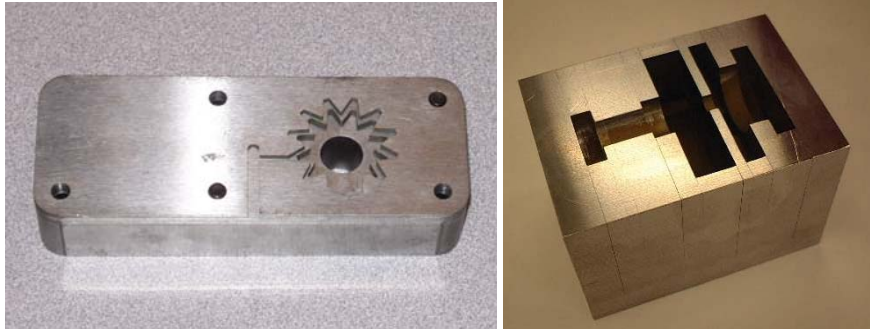


Figure 5: Insert mold for star shaped gear and pattern for sand casting core made with adaptive variable thickness layering.

As we tested different mold designs, we noticed significant time is required to segment the mold in a CAD system. The current commercial CAD packages do not have many tools necessary to perform required tasks. Therefore the segmentation of mold design was relatively time consuming. In order to speed up overall process, we have developed computer software called SliceCAD. SliceCAD provides many useful segmentation and automatic layering tools required for wirePATH process. With SliceCAD, the segmentation will be faster thereby making our wirePATH more practical.

2. SliceCAD- Segmentation tool

Decomposing a complex mold into segments can be complex and the current commercial CAD software are not well suited for this purpose. The purpose of SliceCAD is to create highly accurate manufacturing plans for Wire-EDM of metal segments and layers to form molds directly from CAD data. SliceCAD is a specialized CAD package, which simplifies segmentation and enables layering, and is intended to accompany existing commercial CAD packages. A commercial CAD package is used for mold design, and then SliceCAD is used for segmentation and layering. The segments and layers are then output to CAM software to generate tool paths for Wire-EDM. SliceCAD provides a 3D graphical user interface for viewing, segmenting and layering solid models. SliceCAD is written in C++ and has been developed using ACIS 3D Geometric Modeler and Microsoft Foundation Class Library (MFC). Figure 6 shows how a bottom piece of compression mold was segmented using sliceCAD. The program has many useful tools to extract mold features and to pick points to create cutting planes.

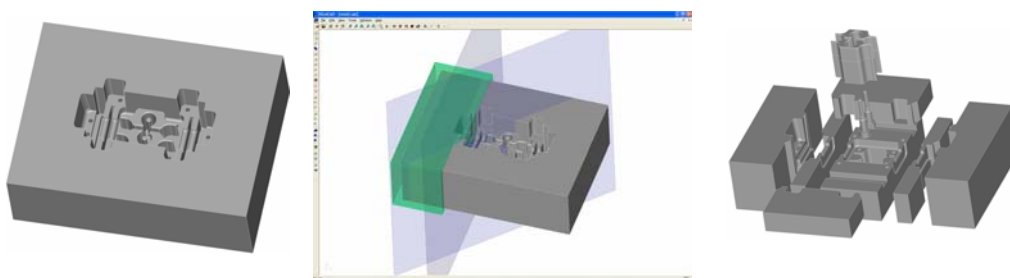


Figure 6: A complex compression mold was segmented using sliceCAD

In wirePATH, there are two modes of segmentation, 3D sectioning and layering. Figure 6 shows the 3D segmentation of a compression mold. This mode is not automatic and a user must decide where he would like to make cuts. The segmentation will require some expertise and knowledge in mold design. If a user prefers to make the mold using layering approach, the layering operation is done automatically. SliceCAD calculates optimal layering scheme based on standard plate thickness and the geometry of the part (shown in figure 7). We can minimize the preparation time by using standard plate thickness. The taper angle of the each layer that is required to approximate part curvature is also computed automatically while minimizing the deviation that is associated with the stepping effect.

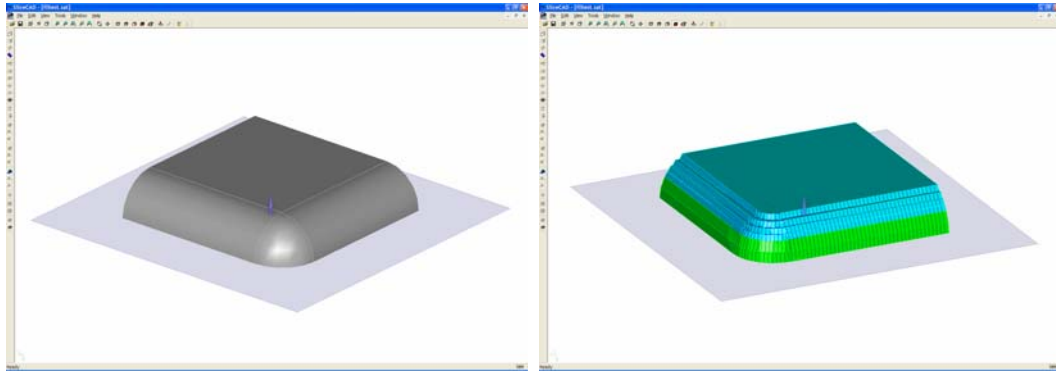


Figure 7: Automatic layering process of sliceCAD

Once all segments or layers have been created, sliceCAD can export the file to different formats. Using wire EDM manufacturing software such as Esprit, exported data from sliceCAD can be used to generate wire path automatically and the manufacturing of segments can begin. By exporting sliceCAD data to stereo lithography (SLA) machine, a prototype of segmented mold can be made to verify mold design before any metal is cut. Problems with assembly process can also be checked. Figure 8 shows some of the rapid prototyped mold pieces for a compression mold.

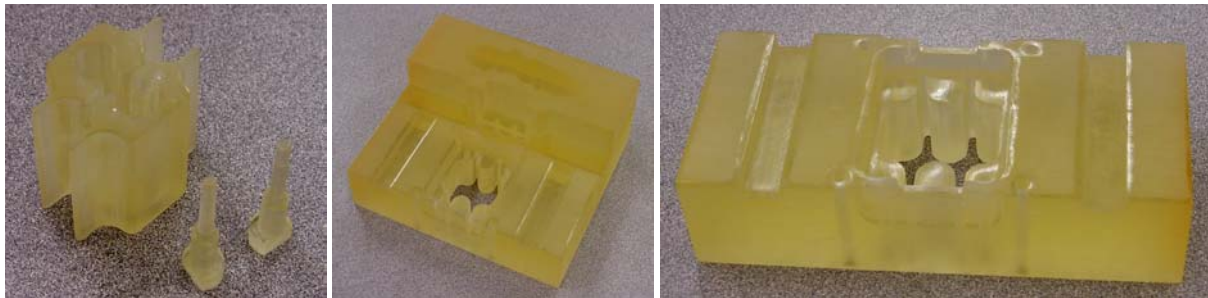


Figure 8: Rapid prototype of mold segments made with stereo lithography machine.

3. Applications of wirePATH mold.

WirePATH can be used for many different mold making applications. It can be applied to injection molding, compression molding, investment casting and making patterns for sand casting. Figure 9 shows some of the parts we have successfully made using wirePATH. The first set of parts in figure 9 is made using injection molding. The second part is made by slip casting. The third part will be made by compression molding.

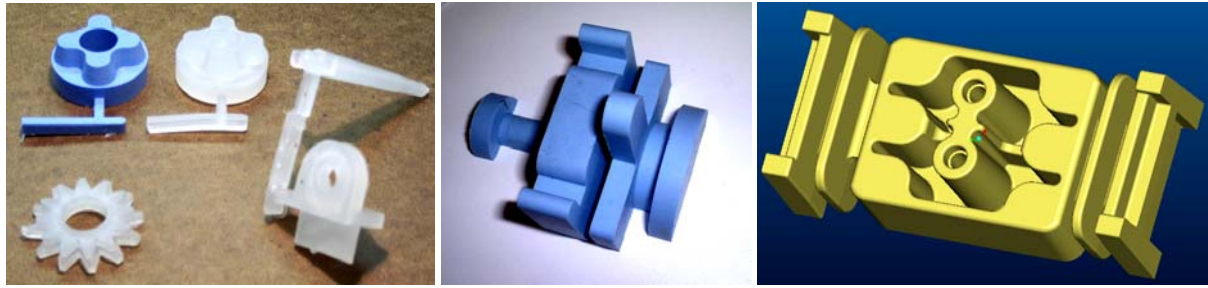


Figure 9: Examples of parts made using wirePATH method.

WirePATH can also be applied to precision micro mold. With wire EDM, no extra effort is needed to obtain high accuracy. We have made a set of micro mold for thin film thermoforming process (see figure 10). This mold has been made in four pieces and assembled together. Over 90% of the manufacturing involved wire EDM. If the part has many complex irregular shapes, layering method can be used and post machining can be done to improve the surface finish.



Figure 10: Micro mold for thermo-forming process made with wirePATH method.

4. Mold Assembly

Molds undergo repeated high load and high stress related operation. Therefore all mold pieces must be held tightly together. However, in order to allow future design changes and repair, mold pieces cannot be permanently bonded together. The assembly relies on two mechanisms. (1) One is the dovetail feature that interlocks two pieces. The dovetails have two purposes, one is for alignment and the other is to provide strength in the assembly. All dovetails are made with high precision wire EDM. By making the dovetails asymmetric and different size, it will ensure that there is no ambiguity in the assembly procedure. Figure 11 shows a typical setup of dovetail system.

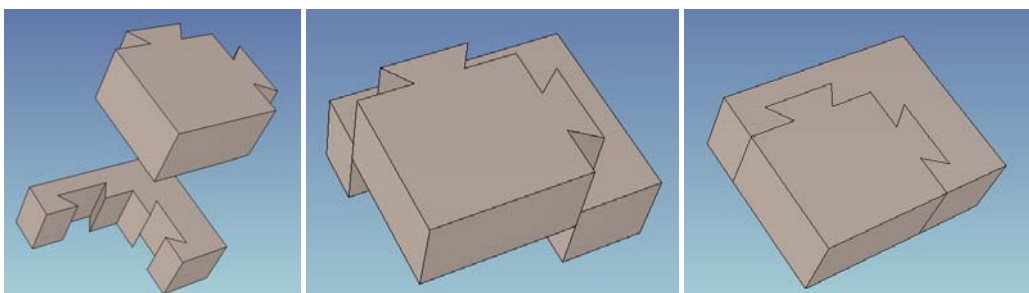


Figure 11: asymmetric dovetail ensure that it can be assembled only one way

(2) Second assembly mechanism is by use of bolts and pins. The SliceCAD program has a dovetail-creating feature that allows a user to pick a size and position of the male and female dovetails. The software then creates the dovetail automatically. From our testing, all parts were held tightly together by using the dovetail and bolts together. Other alternate assembly method is also being studied.

CONCLUSION

A new method of making production mold and patterns for casting was developed. Our patented WirePATH technology is capable of producing molds that is applicable of use in a wide range of applications including sand casting and investment casting as well as injection molding. In wirePATH, the mold is made by assembling precisely manufactured segments. Therefore a part of a mold can be changed to accommodate design changes and repair. We have tested wirePATH on injection molding, micro molds, a sand casting pattern and compression molding. Time saving will vary depending on the geometry and specification of the mold. Our recorded machining and assembly time showed as much as 70% of reduction in manufacturing time when compared to conventional tool making processes. Mold with cavity geometry that is mostly freeform and require fine surface finish may take longer to make the mold using wirePATH. Complex freeform geometry can be created using layering approach, but in order to achieve fine surface finish, a series of post processing steps is required.

SliceCAD was developed to assist a design or manufacturing personnel in mold segmentation and layering processes using a variety of native CAD formats. SliceCAD can be used to make 3D segmented molds or layered molds by using adaptive slicing with variable thicknesses and taper angles. The purpose of SliceCAD is to create high accuracy manufacturing plans for Wire-EDM of metal segments and layers. It simplifies segmentation and enables automatic layering. Unlike layering, 3D segmentation decision must be made by the user. Our research enables new applications of wire EDM to more complex shapes by bridging the gap between CAD, our method, wire EDM and manufacturing processes. Further cases are being tested to refine wirePATH process and to increase its capabilities.

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