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WIRE PATH RAPID TOOLING PROCESS AND SUPPORTING SOFTWARE DEVELOPMENT

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ABSTRACT

Recent developments in Computer Aided Design (CAD) have drastically reduced overall design cycle time and cost. In this paper, wirePATH, a new method for rapid direct tooling, is presented. By using specialized interactive segmentation computer software and wire electrical discharge machining (wire EDM), wirePATH can reduce manufacturing time and cost for injection molds, casting patterns, and dies. Compared to other conventional-mold making methods, wirePATH can reduce fabrication time by as much as 40 to 70%. Wirepath can use a combination of wire EDM and other processes. Our method provides a new means to produce a greater variety in products by changing only portions of the tooling. Segments allow a part of a mold to be replaced to accommodate design changes and repair. WirePATH enables new applications of wire EDM to more complex shapes by bridging the gaps between CAD, our method, wire EDM and conventional manufacturing processes.

INTRODUCTION

With the increasing competition in the global market place and with the growing number of products being introduced, today's industry is under pressure to reduce the time and cost of new product development. Faster product development often means getting to the market faster, establishing a stronger market position, and setting premium pricing. In many industries, rapid product development is now a key aspect of competitive success.

In injection molding and other molding processes, the design and fabrication of the mold consumes a significant portion of production lead-time. The plastic injection molding industry is estimated at $20 billion dollars per year and the current tool and die-related industry is estimated to have annual revenue of about $10 billion [1]. In order to shorten design and manufacturing lead-time, many industrial firms have employed mold analysis software and CAD/CAM packages. However, the mold manufacturing process still relies on conventional mold-making technology, and a significant amount of time is spent on machining, sinker EDM, and labor-intensive polishing.

Many researchers have developed new technologies to speed up mold making processes [1-9]. Direct AIM, Copper Polyamide Selective Layer Sintering (SLS), Direct Metal Laser Sintering, high-speed CNC aluminum tooling, and PolySteel are some of the commercialized technologies. However, they all have some limitations, including a low production rate, limited size, and low production volume. Direct AIM makes molds using the stereolithography (SLA) process. The types of materials that can be used to produce parts are limited to low melt temperature thermoplastics, and the part must be less than 2" in any direction. The major limitation of Direct AIM is that the mold material is not very hard, thus limiting its use to small production runs. The PolySteel process produces mold inserts from a semi-solid polymer/steel compound that is formed directly over a stereolithography part. A mold made with this process does not have good thermal conductivity. Therefore the cycle time is long and the production rate is very slow. Some rapid tooling methods, such as Direct Metal Laser Sintering and aluminum tooling, result in molds that are both soft and weak. Repeated high pressure material flow in the mold cavity causes mold wear, so molds made by these processes do not last very long and are not applicable to parts that require a high production quantity.

WirePATH TECHNOLOGY OVERVIEW

Our patented wirePATH is capable of producing molds that can accommodate a wide range of applications from sand casting and investment casting to high production rate injection molding. WirePATH technology's core components are CAD, geometric modeling and wire EDM. First, a mold is designed in commercial CAD software. Then the 3D CAD mold model is imported into specially designed software called SliceCAD. The mold design is analyzed and segmented into smaller pieces. Then each piece is machined using wire EDM and conventional machining processes. After all the segments are fabricated, they are assembled to form a complete mold (Figure **1**).

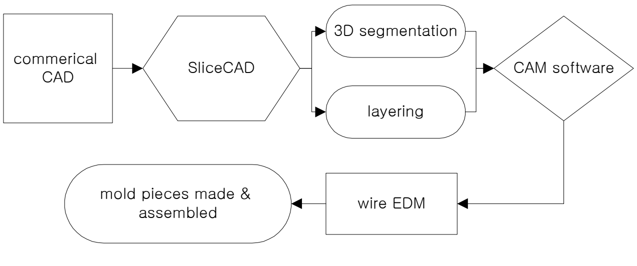


Figure 1: Overview of WirePATH Process

Wire EDM uses a CNC-controlled, electrically charged wire to cut a conductive work piece. Figure 2 shows an illustration of wire EDM cutting. The top and bottom nozzle guide the wire, moving independently to create various taper-angles and faces. Initial machining with high spark-energy settings can produce rough cuts. Then skim cuts can be used to remove a smaller amount of material typically between 0.0002 to 0.002 inches. With a lower flushing pressure and a high wire tension, the wire deflection is reduced, resulting in greater accuracy. Improved tolerance and optimal finishing are achieved by adjusting the spark energy downward to provide slower cutting speeds, resulting in a smoother surface finish. This process can be extremely accurate, with many machines able to move in increments of 40 millionths of an inch (.000004´´) and some 4 millionths of an inch (.000004”). Wire EDM can cut very hard conductive materials easily because cuts are completed using an electrical spark rather than mechanical force. This makes the process ideal for cutting materials with a hardness of above Rc 38. Because the process does not involve force, contact, or deformation, a wire EDM is capable of making walls as thin as 0.005 inches.

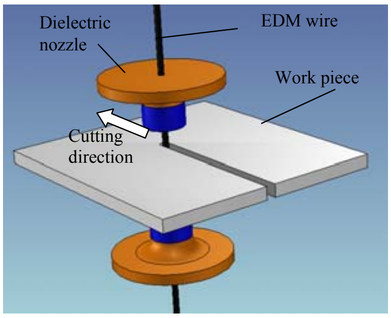


Figure 2: Work Piece is Cut Using Electrically Charged Wire.

The main application of wire EDM is for producing protruded parts such as punches and dies. Wire EDM applications in the mold-making industry have been limited to creating holes and mold repair. Our research enables new applications of wire EDM to more complex shapes by bridging the gap between CAD, our method, wire EDM, and other conventional manufacturing processes. We show that a complex mold can be made using wire EDM by decomposing it into smaller sections. Each section is then made with wire EDM or other manufacturing methods, and all the pieces are assembled to form a complete mold.

1. Different decomposition methods.

WirePATH features two schemes of decomposition. The first mode is to segment mold into 3D segments, and the second is to segment mold using layers.

(1) In the first scheme, the appropriate level of segmentation depends on the type of mold and more importantly its geometry. One extreme 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 3 shows one of the insert molds that was designed and made for injection molding. This mold was made using only wire EDM.

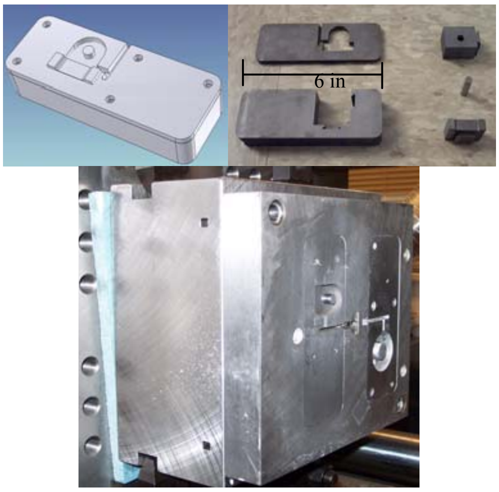


Figure 3 From left **3a**:CAD Model of the Mold, **3b**:All Pieces of This Insert Mold were Made with WireEDM, **3c**:Insert Mold Mounted in the Injection Molding Machine.

Another variation of this method is to use a combination of wire EDM and conventional machining. Complex freeform geometry is best suited to creation using conventional machining, while other geometry, especially deep and narrow cavities, are suited to creation using segments and wire EDM. Hard-to-reach areas can be made easily accessible by segmenting along the narrow cavity as shown in Figure 4. Machining and polishing becomes much easier after segmentation as well. Finishing and polishing are very labor-intensive and can take as much as 30% of the total mold manufacturing time [10]. For some specialized molds, as much as 90% of the machining time is spent on the secondary finishing work. A fine surface finish for an injection mold is very important for easy part release and dimensional accuracy. A typical wire EDM can give a smooth surface finish with multiple passes and skim cutting (up to 0.1 µm Ra), reducing labor-intensive polishing. In skim cutting, less energy is applied to the wire and the spark size is reduced, producing extremely fine finishes and, on some machines, a mirror finish.

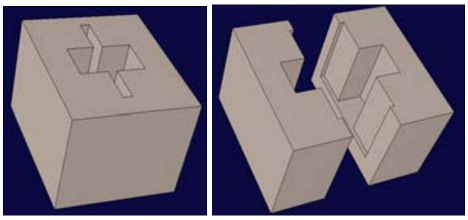


Figure 4: Deep Cavities can be Accessed Easier when Segmented

This segmentation mode provides economic advantages in mold maintenance and repair as well. The completed mold can be rearranged to accommodate different product design changes by interchanging sections of the mold. When parts of the mold wear out or are damaged, that portion of the mold can be replaced, instead of the entire mold having to be made again.

(2) The second segmentation scheme of wirePATH is to use adaptive layering with discrete thicknesses corresponding to available material stock. A mold is segmented using a series of layers as in layer manufacturing (LM). In our layering approach, the thickness of each layer is calculated so that it only uses available standard stock plate thicknesses to minimize preparation time. Furthermore, in order to minimize error caused by the staircase effect of typical LM processes, variable taper angle is used. Figure 4 shows how a curved surface can be approximated by layers with variable discrete thicknesses and variable tapered angles. For a given depth h, different thickness layers are used (d1,d2,d3,…d5). These thicknesses are selected to match one of the standard plate thicknesses available.

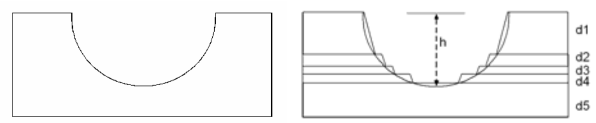


Figure 5: Adaptive Slicing Method with Variable Thickness and Variable Taper Angle.

With a typical wire EDM machine, taper angles of 15^o or higher will require special setup because of poor flushing conditions. Therefore, it is necessary to layer parts so that fabrication does not require cuts with more than 15^o of taper angle. If the taper angle is exceeded, the software will recalculate the layer to conform to the maximum machinable angle. Once all the layers have been manufactured, they can be assembled and finished using sinker EDM or CNC milling to achieve the desired surface finish. For some casting applications where surface quality is not very critical, finishing may not be necessary. Figure 6 shows two molds made using the second segmentation scheme. The first mold shown on the left is for injection molding, made without adaptive slicing. All the layers are the same thickness and there is no taper angle. The mold on the right is a sand casting pattern for a core. It was made using adaptive thickness plates and variable taper angle.

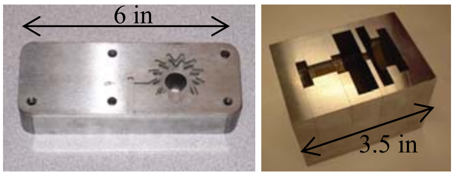


Figure 6: Insert Mold for Star-Shaped Gear and Pattern for Sand Casting Core made with Adaptive Variable Thickness Layering.

As we tested different mold designs, we noticed that a significant amount of time is required to segment the mold in a typical CAD system. Current commercial CAD packages do not have many tools necessary to perform the required tasks; therefore, the segmentation process of mold design is relatively time-consuming. In order to speed up the overall process, we have developed computer software called SliceCAD. SliceCAD provides segmentation and automatic layering functions for the CAD model decomposition phase of the wirePATH process.

SOFTWARE OVERVIEW

Prototype software, called SliceCAD, has been developed to decompose solid models for the wirePATH process. The decomposition phase calculates wire EDMable segments from a solid model, and if necessary, uses layers to approximate the sloped and curved surfaces of the segment. SliceCAD provides functionality that is not available in commercial CAD packages and fits into the overall process as shown in Figure 7.

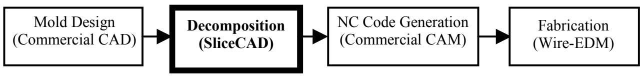


Figure 7: wirePath Process Flow

SliceCAD has been developed in C++ using the ACIS 3D Geometric Modeler (by Spatial Corp.) and Microsoft Foundation Class Library (MFC). ACIS provides support for MFC applications through its Visualization Manager Component (VisMan), as well as rendering and graphical interaction capabilities. ACIS commands are accessed through Application Procedural Interface (API) and Direct Interface (DI) functions. We have designed a number of specialized SliceCAD API functions for model decomposition. The SliceCAD program architecture is shown in Figure 8.

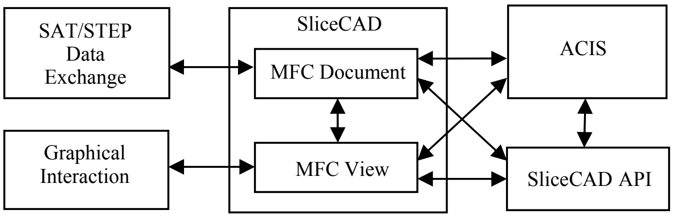


Figure 8: SliceCAD Program Architecture

SliceCAD provides a 3D graphical user interface for viewing, segmenting and layering solid models. The models are saved and restored using either Standard ACIS Text (.SAT) or STEP (.STP/.STEP). Segmentation is performed using the section command, which divides a segment into two or more pieces using a solid that we will label the tool volume. The tool volume is created by the user using reference planes and existing geometry, and defines the shape of the cut that divides the segment. If the segment contains curved surfaces or sloped surfaces exceeding the maximum inclination angle for Wire-EDM, it is approximated using a set of layers. We have designed a new adaptive layering algorithm to create layers with sloping sides that conform to maximum surface error, δ_{max}, and maximum inclination angle, θ_{max}. Layers are computed automatically once the user inputs the build direction, δ_{max}, θ_{max} and a list of constant thickness stock materials. The layering algorithm chooses the layer formed from the thickest material that satisfies both δ_{max} and θ_{max}. In some cases, layers formed from the thinnest material may not conform to δ_{max} or θ_{max}. If θ_{max} is exceeded, we have developed layer reconstruction techniques to produce a conforming layer by altering the layer contours to form a conforming layer. SliceCAD also creates dovetails and injector pin holes to avoid having to transfer the decomposed model to another CAD package before creating the tool paths for the mold.

Once the model has been decomposed, the segments and layers can be saved into a single .SAT file or each can be saved separately. ESPRIT 2002 CAM (by DP Technology) software is then used to generate the tool paths for Wire-EDM. ESPRIT can directly import solids as ACIS .SAT files.

Segmentation

The first step of decomposition is segmentation, which is performed using SliceCAD. Segmentation has previously been used in layered manufacturing to decompose the part to increase fabrication speed and improve accuracy. Krause et al. [11] segment a part to form regions of similar geometric complexity to avoid slicing regions of low geometric complexity with thin layers, which slow fabrication. Others have segmented to increase accuracy by preserving peak features, which include vertices, maxima and minima of curved edges, and maxima and minima of non-planar surfaces [6,12-13]. In our case, segmentation is used to enable fabrication of a part using wire EDM and preserve peak features.

To create wire EDMable segments from a part using SliceCAD, a solid tool volume is defined by the user and Boolean operations are performed using the tool to section the part. A number of methods have been designed for the user to create tool volumes using reference planes and existing geometry. If layering is needed, solids are automatically segmented to preserve peak features before forming individual layers.

Tool volumes are created by sweeping planar profiles to form solid volumes. For reference planes, the tool volume represents the half-space on the normal side of the plane. If multiple planes are used at the same time, the tool volume represents the intersection of the half-space on the normal side of each reference plane. SliceCAD automatically generates a tool volume from a reference plane by constructing a circular profile on the plane and then sweeping it in the normal direction of the plane to form a solid. Proper tool size and location are necessary for the swept tool to cut through the entire solid. The radius of the circle and sweep distance are found from the length of the diagonal of the bounding box of the solid, and the center of the circle is located along the line defined by the center of the bounding box and the normal direction of the plane. A closed loop of edges or planar face defining a planar profile can be swept to form a tool. The sweep direction is the normal of the plane that contains the profile and the sweep distance is determined from size of the bounding box. Once a tool has been created, it may be modified by adding and subtracting volume using a second tool created using the above methods. Segments are formed using the tool to perform Boolean operations on the part. A copy of the tool is intersected with a copy of the part and the tool is subtracted from the part, decomposing the part into two or more new segments.

Before layering, a segment is subdivided to preserve peak features. The subdivision is automated using sampling techniques to identify the positions of the peak features where the segment must be subdivided to produce accurate layers [6,12-13]. Tools are automatically generated at each position and then the solid is segmented.

Layering

Most rapid prototyping processes use layered manufacturing techniques to fabricate parts. Typically, parts are approximated using layers with vertical sides (2.5D layers) and uniform thickness. The goal of research in the area has been to increase part accuracy while at the same time decrease fabrication time. Many techniques require a faceted approximation of the original CAD model. Faceting the model introduces inaccuracy because the facets are created only within a specified tolerance of the actual CAD data. To avoid this inaccuracy, direct slicing has been developed to slice the CAD model instead of a faceted approximation [13-15]. Inaccuracy is introduced when approximating inclined and curved surfaces using stepped or 2.5D layers. During the use of uniform 2.5D layers, the only way to increase accuracy is to decrease layer thickness, which in turn increases fabrication time. A method of using variable layer thicknesses, called adaptive slicing, was developed by Dolenc and Mäkelä [16] for faceted representations, and Suh and Wozny [13]for direct slicing, which Kulkarni and Dutta [6] extended. In adaptive slicing, areas of higher geometric complexity are approximated using thinner layers, while areas of lower geometric complexity are approximated using thicker layers. Jamieson and Hacker used a method to compare the geometry of successive contours [14]. Sabourin *et al.* used stepwise uniform refinement to first subdivide the model using the thickest possible layers, and then further subdivide each layer until the surface tolerance is satisfied. Other researchers predicted layer heights using the cusp height and local geometry [6,13,16-18]. Many have proposed the use of layers with sloping sides [12,15,17-19]. Sloping layers allow part accuracy to be maintained over 2.5D using thicker layers, or to be increased using the same thickness. Some methods use sloping layers with adaptive slicing [12,17,18].

We have designed a new adaptive layering algorithm that uses direct slicing in ACIS along with sloping layer sides that can be produced using our 4-axis wire EDM. The layering algorithm provides a more accurate measure of surface error than do conventional methods and allows for layer reconstruction to conform to our process limitations, mainly the maximum inclination angle of the wire EDM. Since the wire EDM produces ruled surfaces, other surfaces must be approximated using a set of discrete thickness layers having a constant thickness and sloping sides. Surface quality increases with thinner layers as does production time, so the optimal set of layers is the thickest set of layers that can be produced using wire EDM that satisfies δ_{max} and θ_{max}. If a layer formed using the thinnest material cannot be machined with wire EDM without exceeding θ_{max}, the layer is reconstructed so that it can be machined without exceeding θ_{max}. Reconstruction always adds material to the layer so that it may be finished using another process.

The new layering technique checks both δ and θ against straight line segments, called match lines. Match lines are formed between sampled positions on the top and bottom contours of the layer and are used as guides when creating the ruled layer. A solid layer is formed by intersecting a planar slab with the segment. The top and bottom contours of the solid layer are extracted, and each edge in the top contour is matched to an edge in the bottom contour using the topology of the solid layer. Match lines are formed by constructing a straight line segment between a sampled point on one of the edges of the top contour and a sampled point on the matched edge of the bottom contour. An adaptive method, based on the work of Suh and Wozny [13], is used to calculate the distance between sampled points on each edge. The proportion of the distance between two consecutive sampled points and the length of the edge is computed for both edges, and the smaller ratio is used to recompute the distance between sampled positions on the opposite edge. As the match lines are formed, θ_{max} and δ are checked. The angle, θ, between the match line and the build direction is computed and compared against θ_{max} as shown in Figure 9. Instead of predicting δ using local geometry and approximation, the distance between the original surface and the match line is found at a number of sampled positions on the surface using a curve, C, as shown in Figure 9. The curve is found by intersecting a plane with the surface adjacent to both the top and bottom edges. The normal of the intersecting plane is found using the cross product of a vector formed using the match line and the face normal at one of the endpoints of the match line. This technique is significantly less likely to miss extreme vertical curvature changes than past methods, since a curve from the actual surface is analyzed and not approximated with a circular arc using the vertical curvature approach.

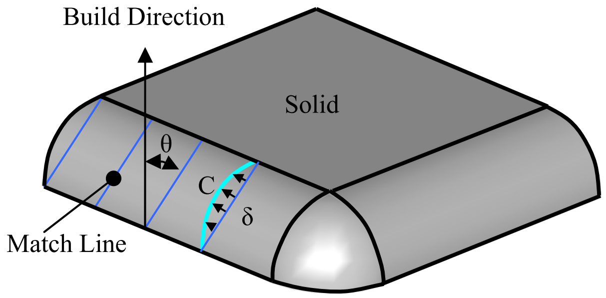


Figure 9: Checking Maximum Angle and Surface Error Using a Match Line

If all the match lines are accepted, a solid layer with ruled sides is formed. A solid between the top and bottom contours is skinned using the match lines as guides for the ruled surface generation. If θ_{max} is exceeded for a layer using the minimum thickness material, the layer must be reconstructed to conform to θ_{max}. If reconstruction is possible, material will be added to the layer, allowing for finishing of the fabricated layer. If the layer cannot be reconstructed, the profile of the layer is found at the mid-height of the layer and swept along the layering direction to create a stepped layer. A layer is reconstructed by altering its match lines to conform to θ_{max} and then fitting new curves through the endpoints of the reconstructed match lines. If the face adjacent to both top and bottom edges is planar, a new straight edge will be fitted between the reconstructed match lines, and the reconstructed face will remain planar. If the face is non-planar, each match line is reconstructed to conform to θ_{max}, if necessary, and a spline curve fitted through the endpoints of the match lines.

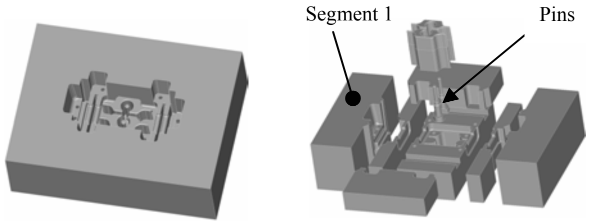
The layering algorithm, summarized in Figure 10, computes a set of layers satisfying both δ_{max} and θ_{max} from a set of discrete material stock thicknesses, m_i, ranging from m_{high} to m_{low}. All layers should conform to one of the available thicknesses, although in some cases one of the layers must be machined to a different thickness to maintain the original height of the part. Layering begins after a build direction is defined. The z-axis is assumed to correspond to the build direction.

1. Find z_{low} and z_{high} for the segment and use the difference to initialize the remaining segment height, $h_{segment}$.
2. Initialize $z_{current}$ to z_{low}.
3. Initialize the current material, $m_{current}$, by finding the thickest material in the lis that is not thicker than $h_{segment}$. If $m_{current} < m_{high}$, set $m_{current} = h_{segment}$. If $m_{current} < m_{low}$, re-compute the previous layer using $m_{current} = h_{segment}$ from the previous step.
4. Create a solid layer by intersecting a slab (with thickness equal to $m_{current}$) with the model.
5. Match the edges of the top and bottom contours using topological information.
6. Sample the matched edges of the contours to find match lines.
7. As each match line is created find θ and compare it to θ_{max} .
8. If $\theta > \theta_{max}$ and $m_{current} > m_{low}$, reject the layer and restart at step 4 with $m_{current}$ set to the next thinnest material in the list. If $m_{current} = m_{low}$, reconstruct the layer to conform to θ_{max}.
9. If θ_{max} was not exceeded, check δ, and if it is exceeded, reject the layer and restart at step 4 with the $m_{current}$ set to the next thinnest material in the list. If $m_{current} = m_{low}$ and δ_{max} is exceeded, accept the layer and alert the user to the problem.
10. If the layer is reconstructed or accepted, form the ruled layer using ACIS. Then, subtract $m_{current}$ from $h_{segment}$
11. If $h_{segment} > 0$, add the $m_{current}$ to $z_{current}$ and start over at step 3.

Figure 10: Layering Algorithm

Examples

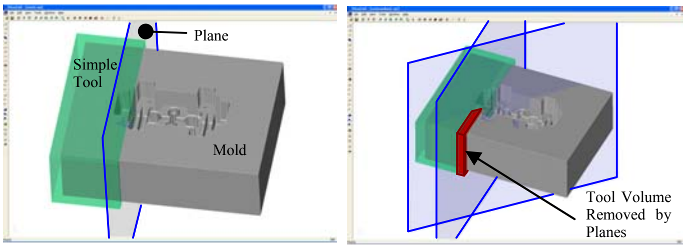
The mold of Figure 11a is manually segmented into the parts shown in Figure 11b for creation using wire EDM. All of the parts shown in Figure 11b can be segmented using SliceCAD, except two pins, which must be designed as separate parts during the mold design due to their complexity.



(a) Example Mold (b) Segmented Mold

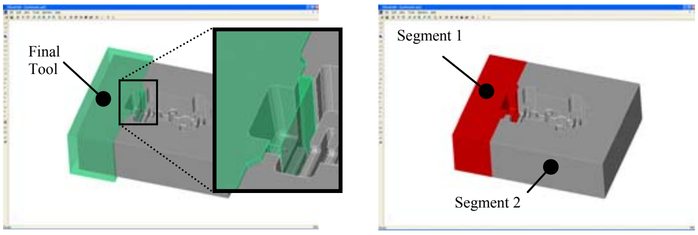
Figure 11: A Mold Before (a) and After (b) Segmentation

Segment 1 of Figure 11b is created by sectioning the mold with a tool made using reference planes. The first step to create the final tool is to create a simple tool using a single reference plane as shown in Figure 12a. Then material is removed from the simple tool using additional reference planes as shown in Figure 12b. The final tool used to create Segment 1 is shown in Figure 13a and has been formed by removing material using additional reference planes. Figure 13b shows the two segments resulting from a section using the final tool of Figure 13a. Segment 1 is formed from the intersection of the final tool with the mold, and Segment 2 is formed by subtracting the final tool from the mold.



(a) Tool Creation Using Single Plane (b) Tool Modification Using Planes

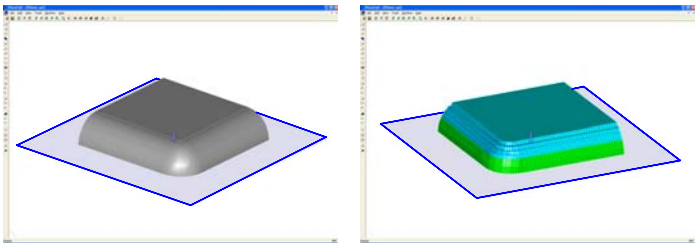
Figure 12: Tool Creation and Modification



(a) Final Tool (b) Section Made Using Final Tool

Figure 13: Final Tool and Sectioned Part

In some cases, a segment must be layered to produce ruled approximations to non-ruled surfaces. The part shown in Figure 14a is layered using the new adaptive slicing method described above. For this particular part δ_{max} is 0.01”, θ_{max} is 30°, and layer thicknesses of 0.125”, 0.250”, 0.375”, and 0.500” are used. The result of the layering process is shown in Figure 14b. The bottom two layers fall within δ_{max} and θ_{max} using a 0.250” material and the top four layers are reconstructed for exceeding θ_{max} using 0.125” material.



(a) Segment and Reference (b) Layered Segment

Figure 14: Layering a Segment

Once all segments and layers have been created, SliceCAD can export the file using different formats. Using computer aided manufacturing (CAM) software such as Esprit, exported data from SliceCAD can be used to generate wire tool paths automatically. Before the wire EDM process, SliceCAD data can be uploaded to a stereolithography (SLA) machine in order to create a prototype of a segmented mold. This prototype can be used to verify the design before any metal is cut. Figure 15 shows some of the rapid prototyped mold pieces for a compression mold.

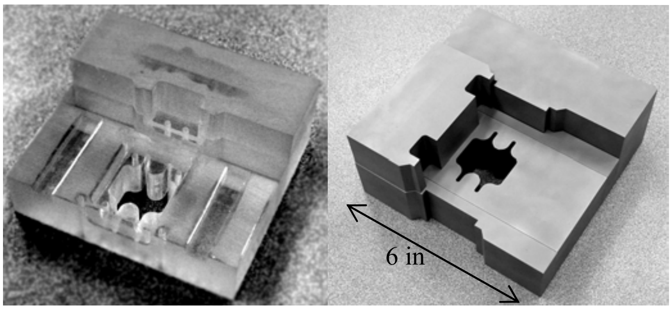


Figure 15: *Left*: Rapid Prototype of Mold Segments Made with Stereo lithography Machine, *Right*: Mold Pieces Made with WireEDM.

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 16 shows some of the parts we have successfully made using wirePATH. The first set of parts in the figure is made using injection molding, while the second part is made by slip casting. The third part is a part we are currently working on, and it will be made by the compression molding process.

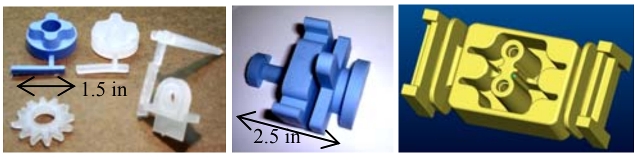


Figure 16: Examples of Parts Made Using wirePATH Method.

WirePATH is well suited for making a precision micro mold because no extra effort is needed to obtain high accuracy with wire EDM. We have made a micro mold for the thin film thermoforming process (see Figure 17). Over 90% of the manufacturing involved wire EDM.

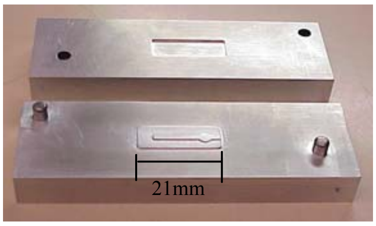


Figure 17: Micro Mold for Thermo-forming Process Made with wirePATH Method.

The actual processing time for WirePATH, including setup, machining, Wire EDM and assembly, was recorded. Then the detailed CAD drawings of the molds were sent out to different machineshops and machinists. Their estimates on the manufacturing time were averaged. According to this comparison, it showed that wirePATH can make the molds 40% to 70% faster.

4. Mold Assembly

Molds undergo repeated temperature fluctuation and high stress. 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. WirePATH assembles segments using dovetails and a combination of pins and bolts. The dovetail interlocks pieces, providing alignment and strength in the assembly. All the dovetails are made with high precision wire EDM to ensure a proper fit. Making the dovetails asymmetric and different sizes will ensure that there is no ambiguity in the assembly procedure. Figure 18 shows a typical setup of a dovetail system. Bolts and pins are used to provide additional strength. The SliceCAD program has a dovetail-creating feature that allows a user to pick the size and position of the male and female dovetails. The software then creates the dovetail automatically. From our testing, all the parts were held tightly together by the use of the dovetail and bolts together.

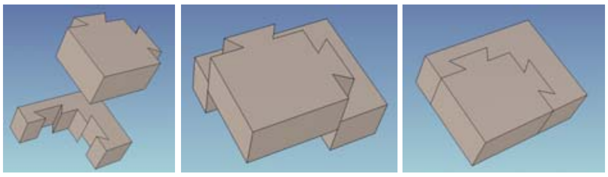


Figure 18: Asymmetric Dovetail Ensure That They Can Be Assembled Only One Way

CONCLUSION

A new method of making segmented tooling has been developed. WirePATH technology can be used in a wide range of applications including sand casting, investment casting, and injection molding. In particular, production molds and patterns for casting have been developed and demonstrated. In wirePATH, the mold is made by assembling precisely manufactured segments, which are generated by decomposition of a CAD model. Segments allow a part of a mold to be replaced to accommodate design changes and repair. The overall time saving will vary depending on the geometry and specification of the mold. A mold with a cavity that is mostly freeform and requires fine surface finish may take longer to make using wirePATH. Complex freeform geometry can be created using the layering approach, but in order to achieve a fine surface finish, a series of post processing steps are required. We have tested wirePATH on injection molding, micro molds, a sand casting pattern, and compression molding. Our estimate showed as much as a 70% reduction in manufacturing time when compared to that of conventional tool-making processes. Parts with complex freeform shapes, while requiring fine surface finish, may not be suitable for the wirePATH process.

We also developed SliceCAD, software which assists design and manufacturing personnel in mold segmentation and layering processes using a variety of native CAD formats. 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. SliceCAD can be used to make 3D segmented molds or layered molds by using adaptive slicing with variable discrete thicknesses and variable taper angles. With SliceCAD, the segmentation is faster and easier, thereby making our wirePATH process more practical. Our research enables new applications of wire EDM to more complex shapes by bridging the gap between CAD, our method, wire EDM, and conventional manufacturing processes. Further cases are being tested to refine the wirePATH process and to increase its capabilities.

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