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Rapid Prototyping of EPS Pattern for Complicated Casting

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Abstract

In Rapid Prototyping (RP) process the 3D object is approximated into several 2D slices. All these slices are of a uniform thickness hence called uniform slicing of zeroth order approximation. Such a system always suffers with the staircase defects. Very thin slices have to be used to minimize these defects, which increase the production time. In this work, a RP system called Segmented Object Manufacturing (SOM) is used to produce the Expanded Polystyrene (EPS) pattern, which uses adaptive slicing with higher order approximation. This system uses the concept of visible slicing in which a complicated object is produced by converting it into the accessible (visible) segments. This is a hybrid system for producing EPS patterns which utilizes the advantages from subtractive and additive processes. These EPS patterns found their application in Evaporative Pattern Casting (EPC). EPS bracket is produced by SOM machine to prove the capability of the system.

Keywords: Rapid Prototyping, Expanded Polystyrene, Evaporative Pattern Casting

Introduction

Rapid Prototyping process is capable to produce objects directly from the CAD model. In RP a complicated 3-D object is converted into 2-D slices and assembled layer by layer to get the final part. Rapid Prototyping combined with allied technology gives freedom to develop complicated metallic objects. The combination of RP and traditional metal casting process is called Rapid Casting *(RC).* This gives opportunity to develop rapid tooling for casting to simplify the process. In most of the cases the cores, patterns and cavities can be produced and topology optimization of the complicated casting can be done by RC. Greenbaum et al. [1] presented paper in European Conference (1993) on Rapid Casting and discussed the commercial use of Rapid Prototyped pattern in Investment Casting *(IC).*

IC is a precision casting process which employs wax pattern as sacrificial pattern to produce solid-metal parts. These sacrificial patterns are used to create a ceramic mould by investing refractory ceramic coatings on the patterns. The Selective Laser Sintering *(SLS),* Fused Deposition Modelling *(FDM),* StereoLithography *(SL)* and Inkjet Printing (Model Maker II) systems have been found capable of producing wax patterns, which can be used directly in IC [2].

Evaporative Pattern Casting (*EPC*) process gives flexibility to produce complex geometries by integrating several parts in single casting. The EPC is capable to produce thin walled castings of sound quality and tight dimensional accuracy can also be achieved. Jordan et al.[3] has produced ductile iron of 0.09” section size by EPC process. Conventional production of foam patterns is a three-step process: pre-expansion of expandable polystyrene (PS) beads to make a pre-puff of correct density, followed by stabilization or aging and finally moulding of the foam beads into the desired pattern shape [4].

The RP process gives an opportunity to explore the different pattern making processes. EPS pattern making which includes foaming, molding, manual cutting, CNC machining and rapid prototyping are discussed by researchers [5]. Freeform Automated Sculpting Technology (FAST) is a system used to produce EPS pattern [6]. The system consists of Laser Scanner, CAD/CAM package, Six-axis Kuka KR6 industrial robot and an electrically heated cutting tool. This system is capable to produce the moderate complex parts but it’s difficult to justify the cost of the sub systems. Researchers at American University of Beirut in Lebanon developed a system called Model Angelo [7]. It utilizes a combination of rotational and linear axis to cut foam with a heated cutting tool. The block is held with the rotating fixture and its motion is synchronized with the cutting tool. TruSurf is a layered manufacturing method developed by Hope et al [8] at the Department of Mechanical Engineering, University of Queensland, Australia. This is a five-axis high pressure water-jet cutter and it is used to cut the model’s cross-sections from layers of polystyrene. The system is not fully automatic as assembly is done manually. Very complicated parts cannot be produced by this system but the process is cheaper as compared to FAST. Broek et al.[9] has developed Freeform thick-layered object manufacturing (FF-TLOM) system, this system is very similar to the TruSurf. The basic difference between both of the processes is that FF-TLOM has flexible cutting tool, which gives the scope of high order approximations of the desired surface. As all these machines utilize a taut hot wire cutting tool which greatly restricts the geometry which can be sculpted. The most important drawback of almost all processes is that if the thickness of the sheet is more than 4mm the temperature gradient will come in picture and affect the surface finish and quality of the product. These all processes are capable of the first order approximation of the surfaces only.

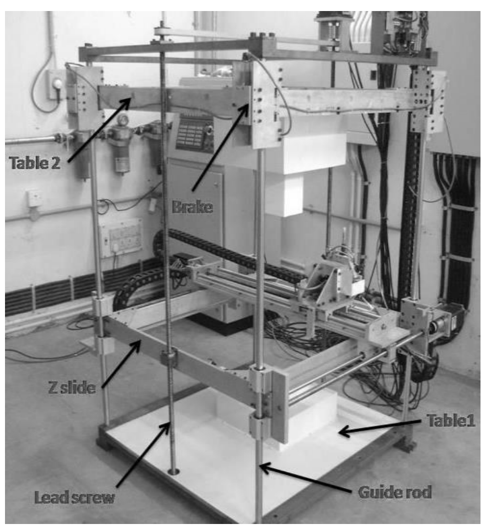


Figure 1 Architect of SOM machine

In this work, a RP system called Segmented Object Manufacturing (SOM) as shown in figure 1 is used to produce the Expanded Polystyrene (EPS) pattern, which uses adaptive slicing method with higher order approximation. This system uses the concept of visible slicing in which a complicated object is produced by converting it into the accessible (visible) segments. This is a hybrid system for producing EPS patterns, which utilizes the advantages from subtractive and additive processes. A bracket pattern is produced by SOM machine to prove the capability of the system.

Methodology

The SOM machine belongs to the category of adaptive slicing with higher order approximation. The complicated model is converted into the segments by Visible Slicing approach. In figure 2 the possible set of V-Slices are shown and figure 2(d) has the V-Slice with minimum amount of raw material requirement. The SOM machine has three sub-system: machining, hot wire slicing and gluing. The Kinematics of SOM machine is shown in the figure 3. It has two tables, one is at the top and other is at the bottom. Bottom table is fixed and top table can slide up and down on four guide rods. The pneumatic spindle and hot melt glue dispensing system is mounted in between the top and bottom table and can move in all three directions. The spindle is attached with a pneumatic indexing system for orienting the cutter in upward and downward direction as per the requirement.

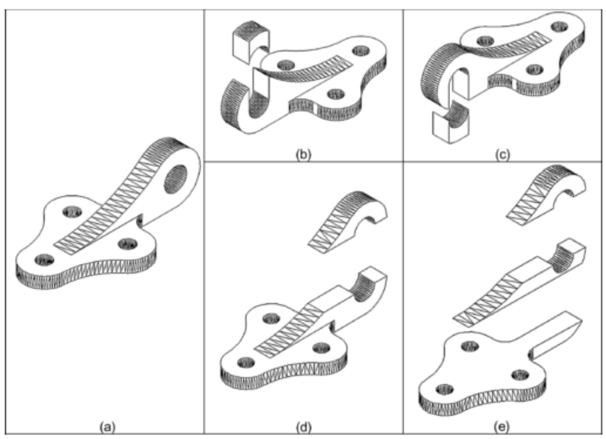


Figure 2 (a) the object; (b) one possible set of V-slices; (c) another possible set of V-slices; (d) V-slices with minimum amount of raw materials; and (e) the V-slices and horizontal levels

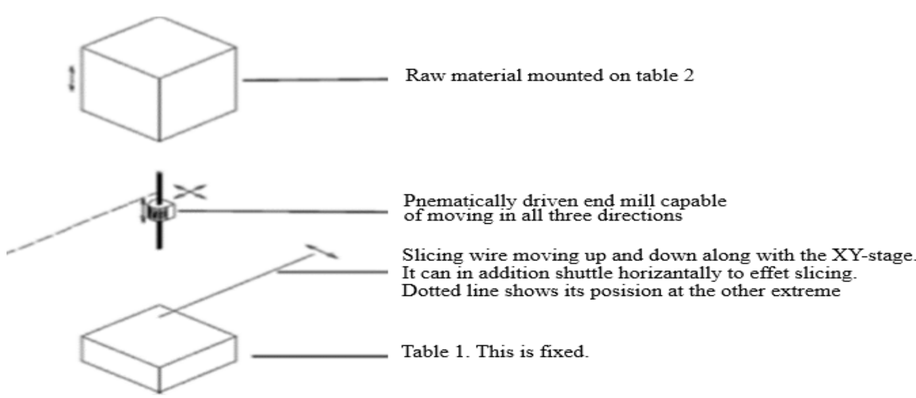


Figure 3 Kinematics of SOM machine

<u>Experimental Setup</u>

The Segmented Object Manufacturing is a system developed to produce the complicated objects with internal features. This is an Additive Manufacturing process, in which the object is converted into segments, and the slicing is adaptive with higher order approximation. The V-slicing approach converts an object into segments, and after slicing the internal feature can be built. In SOM machines two cutting systems are available, one is hot wire for slicing and another one is machining tool. For slicing, Nicrome wire (28 SWG) and transformer of power rating 24V, 3A AC is used. Hot melt glue gun is used to disperse the adhesive for assembly of the component.

(a)

(b)

(c)

(d)

Figure 4 Different types of cutter available for EPS machining **(a)** Diamond deburring cutter**, (b)** Cylindrical deburring cutter, (c) Cylindrical flat end deburring cutter and (d) Flat end milling cutter

Tool Selection for Machining

Selection of correct tool for machining is very important. Different types of cutters are available for machining. The deburring cutters give better finish for EPS patterns as compared to normal cutters. The diamond deburring cutter as shown in figure 4 (a) is selected and used for machining EPS pattern.

Path Planning for Machining, Slicing and Gluing

As the SOM is an automatic system with hybrid features, it has three sub-systems and path planning should be done for all these sub-systems to make it fully automatic. Tool path planning for milling cutter and glue dispensing system is done by Powermill software. There are different machining strategies available and based on these strategies tool path planning is done. Figure 5 shows the flowchart for complete code generation for SOM machine to produce bracket.

After slicing the CAD model with help of PowerShape, segments of the CAD model are imported in Powermill (CAM). In the case of bracket the number of segments are two, so two segments are imported. The bounding box has to be defined to calculate the dimensions of the EPS block required to produce bracket. Figure 6(a) shows the tool path for machining outer feature of the bottom segment. Similarly tool path planning for internal feature of the bottom segment is done. The tool path planning for the outer and inner feature is shown in figure 6(b).

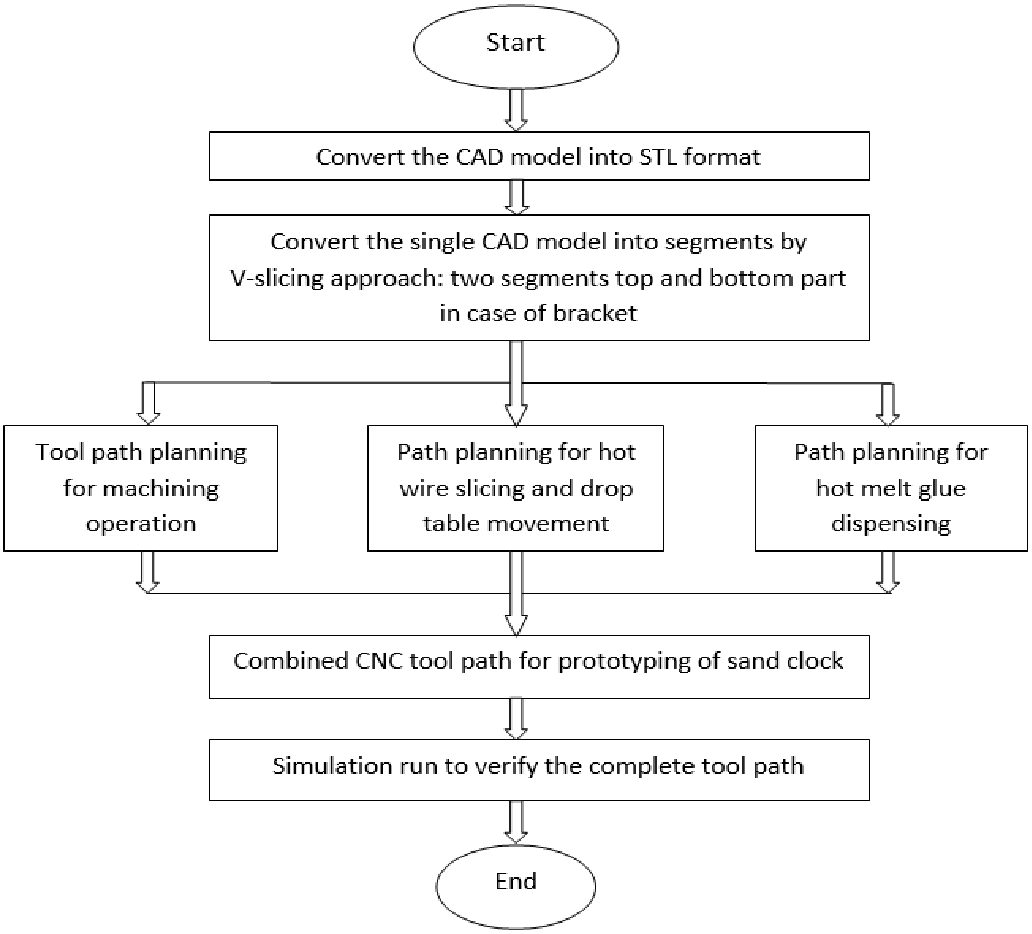
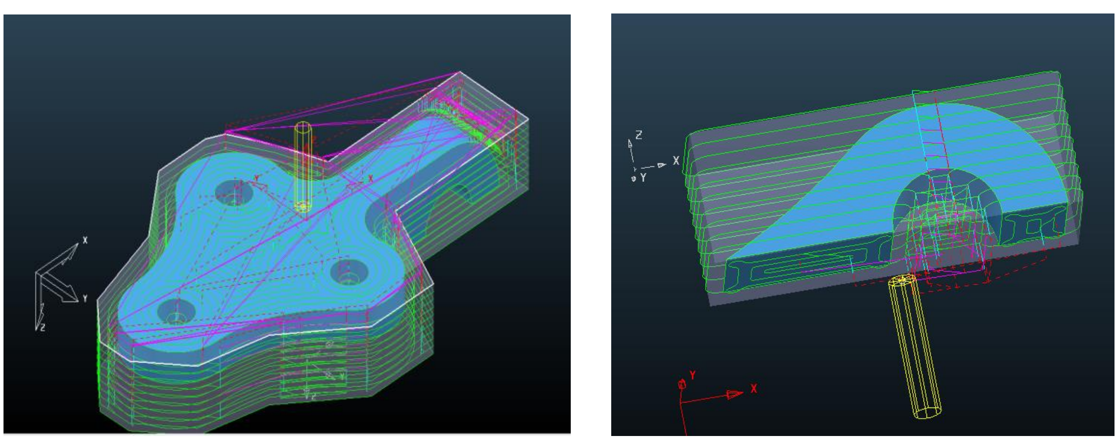


Figure 5 Flowchart of Complete Tool Path Generation and Simulation Run for Bracket

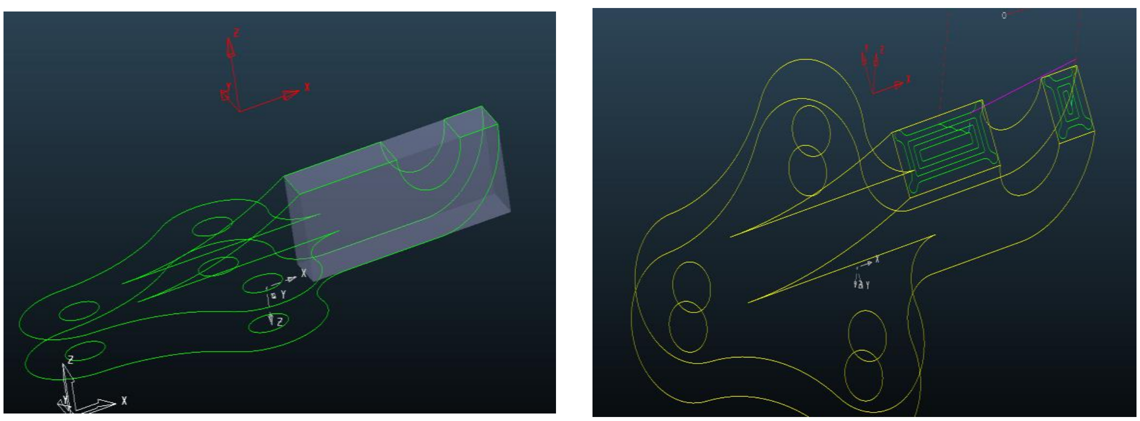


(a) (b)

Figure 6 Tool Path Planning (a) Outer Feature of the Bottom Segment (b) Internal Feature of the Top Segment

As the hot wire slicing moves in XY plane only, the path planning of slicing is very simple. First step is just to find out the Z height of the block where slicing is required. After getting the Z axis position the top table of SOM machine is parked at that height and slinging is done. The G-code written for slicing is combined with CNC machining code.

All CAM packages give option to generate tool path planning for machining operation, so for glue dispensing the modification is required in the tool path. First the glue dispensing area is decided and box is created as shown in the figure 7(a) and path planning is done. The G-code is modified using CIMCO software and the glue dispensing path is generated as shown in figure 7(b).



(a) (b)

Figure 7 Glue Gun Path Planning (a) Bounding box (b) Modified Tool Path

Steps for Rapid Prototyping of Bracket on SOM Machine

The steps of bracket making using SOM machine is shown in figure 8:

Step0. EPS block is clamped at top table using double sided tape.

Step1. The Cutter can be rotated vertically with 180 degree indexing mechanism. The cutter is indexed upward to machine visible bottom contour.

Step2. After bottom contour machining the top table is moved downward and parked at particular height.

Step3. The hot wire cutter can move in XY plane, using this cutter slicing is done at particular height.

Step4. After slicing the object is in two segments, one segment is attached at the bottom table and other is moved upto the predefined top position.

Step5. The cutter machines the internal feature of the bottom segment.

Step6. The cutter is indexed at upward direction to machine the internal feature of the top segment.

Step7. After machining the bottom visible contour, the automatic glue dispensing system is used to apply glue on to the bottom surface and the top table is moved downward and parked at particular height to assemble two segments.

Step8. After assembly, the final slicing is done using hot wire cutter.

Step9. The top table moves upward to reach the particular height.

Step10. The visible part is machined to get the final part.

Step11. The bracket is removed from the machine.

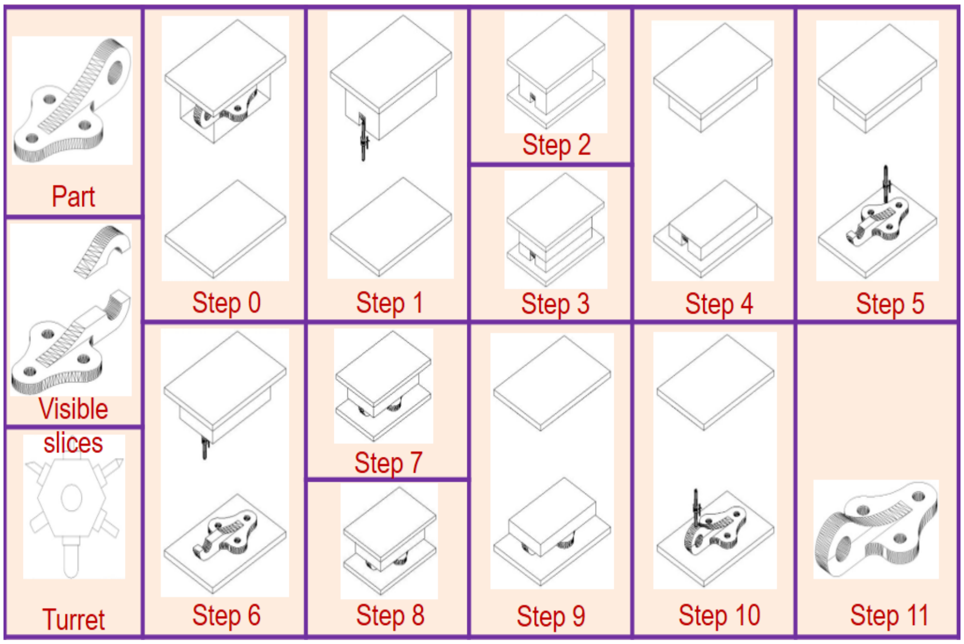


Figure 8 Steps for Rapid Prototyping of bracket

(a) (b)

Figure 9 (a) CAD model of the bracket (b) Rapid Prototyped EPS pattern

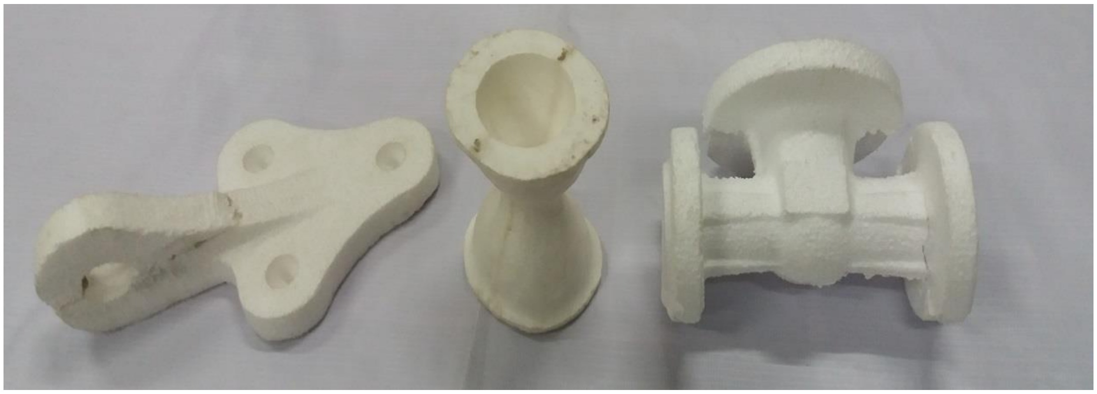


Figure 10 EPS Patterns Produced on SOM Machine by V-Slicing Concept

Sand clock and Valve are also produced on SOM machine as shown in figure 10. The SOM machine is capable to produce complicated shapes with internal feature. The V-Slicing concept converts an object in segments and internal features are accessible to the cutter after slicing.

Conclusion

In this work, a RP system called Segmented Object Manufacturing (SOM) is used to produce the Expanded Polystyrene (EPS) pattern, which uses adaptive slicing method with higher order approximation. Architect and working principle of SOM machine is explained. The Visible Slicing concept is used to convert a complicated object into visible segments. The bracket is converted into visible segments and tool path planning for machining and slicing is done. Automatic glue dispensing system is used to assemble the two segments of the bracket. Full code is generated for SOM machine to produce EPS pattern and the bracket is produced, which proves the capability of the system. As the quality of the patterns produced by SOM machine is not very good, so the improvement in overall quality is the primary requirement. In the future work, the optimization of machining and slicing parameters will be done to produce good quality patterns by achieving better dimensional, geometrical accuracy and surface finish.

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