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Parameterized Modeling of Blow-Moulds for Designer PET Bottles

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ABSTRACT

This work describes a technique for producing blow-moulds for Poly Ethylene Terephthalate (PET) bottles decorated with ornamental patterns. The design is initiated by generating a set of parameterized tile elements and by arranging them into some definite order to create andecorative pattern. The pattern is mapped toroidally around the central part of the PET bottle. The top and bottom sections of the bottle mould half are also created and assembled with the decorated middle section. Moulds can then be fabricated by rapid prototyping or by NC-milling.

Keywords: blow moulds, PET bottles, decorative tiling patterns, toroidal bending.
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1 INTRODUCTION

Blow-mould, a production tool in the blow forming process, is commonly employed for manufacturing of PET bottles. The blow-mould is made in two similar halves and each half consists of three sections (top, middle and bottom) having cavities corresponding to the three portions of the bottle (dome, center and base). PET bottle is produced by inflating a hot and hollow thermoplasticpre-form inside the blow-mould. Air pressure inflates the thin walled pre-form and forces it outwards against the blow-mould sides, as depicted in Figure 1.

PET bottles are used in the packaging of drinks, food stuffs and personal care products. Most of PET bottles available in the market consist of a very common design of circumferential ribs. This type of bottle has a very uniformappearance, thus decreasing aesthetics and the commercial value of the product in the bottle. It is desirable to adorn the beverage bottles in order to increase the level of aesthetic appeal, and this has become one of the goals of the bottle making industry.

Our intention here is to simplify the production of designer PET bottles. We focus our prototype demonstrationon bottles with a hyperbolic surfacein its central portion; they are called waist bottles (Fig. 2). In this center section there are two opposite curvatures going in two different directions. Our work focuses on the decoration of these waist bottles by embedding a pattern around the waist. The shape of the PET bottle is defined by the shape of the blow-mould cavity. The specific challenge is thus to mapa desired tiling pattern onto the hyperbolic surface of the mould half cavity. A semi-automatic modeling approach is described to produce the blow-moulds which in turnare utilized to generate PET bottles decorated with the tiling patterns. The modeling process is initiatedby generating a set of parameterized tiling elements and by arranging them into some definite order to create a desired pattern.Thispattern is then bent toroidally through an angle of 180 degrees about the rotational symmetry axis of the bottle. This toroidal bending transforms the planar (zero curvature) tiling pattern into the hyperbolic curvature (negative curvature). In our CAD model, the stock material is added around the toroidally bent pattern by sweeping a suitable outer cross section along the trajectories of the bent pattern. Finally, thedecorated middle section of the bottle mould half can be viewed as a hyperbolic cavity from which an ornamental pattern has been extruded in bas-relief.

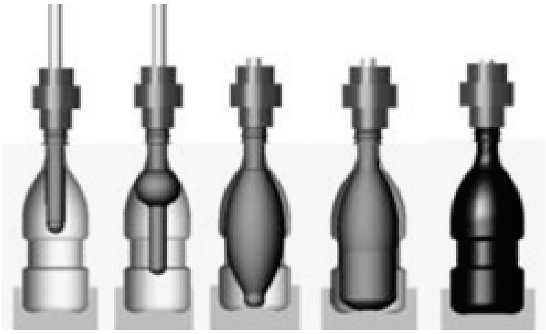


Fig. 1: Inflation in the blow forming process.

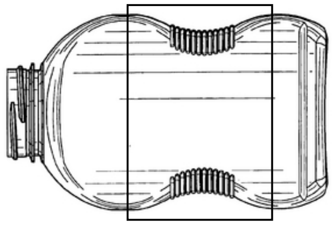


Fig. 2: Waist bottle showinghyperbolic curvature in the central portion.

In order to meet the demand for novelty in PET bottles, a parameterized pattern generator has been developed that produces a variety of tiling patterns with appropriate definitions of various modeling parameters. Thisparameterized modeling allowsquick initial design and fast modifications and provides the means tocreatecustom-design blow-mouldswith minimal effort. Since the modeling data can be transferred automatically from the design to the manufacturing stage, the production of the blow-moulds will not consume much extra time.

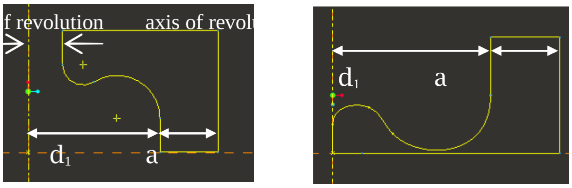
2 LITERATURE REVIEW

Various modeling techniques have been employed in thecomputer-aided design and manufacturing of bottle blow-moulds.Chua [1] developed a customized application program to create a library of "bottle-design" features and to integrate design and manufacturing of a bottle blow-mould usingproprietary CAD/CAM software named Duct5. Xu [2] focused on the plastic forming processes, mainly on the molding processes and highlighted the use of CAD/CAM technology for the plastic industry.Johnston [3] presented a blow-molding prototype system, wherein a geometric model of hollow plastic container of a desired contour is first designed and then used to generate a geometric model of the corresponding mould cavity using CAD software.William [4] created a blow-molded transparent container decoratedwith a customized label or sleeve. Yourist [5] presented a method for designing and manufacturing a blow-molded container withhighly artistic sculptural relief.He graphically designed a container skin shape, created 2-D artwork designs, added 3-D relief to the artwork designs, and applied the artwork to the container skin.Tam [6] designed and developed a surface scanning system for capturingsome point-cloud data set, which could then be post-processed by a CAD system to construct a surface model of the scanned object. The created CAD model then facilitates the design and manufacturing of blow-moulds.Cho [7] presented a parametric feature and knowledge-based design system consisting of different modules. Using these modules, blow-mouldswere created in a highlycustomized manner. Masood [8]described the results of design, analysis and optimization of bottle shapes using Pro/Engineer and Pro/Mechanica.Singh [9] discussed the importance of the computer integrated manufacturing system for plastic parts; he also described available engineering tools for increasing productivity. Candal [10] presented methods for the design and analysis of plastic pieces and their molds using CAD/CAE tools. Whybrew [11] applied a parametric approach in the design of tire mould engraving. Chu [12] described a parametric design system for the production of tire molds and created 3-D mold models in an integrated CAD/CAM system.

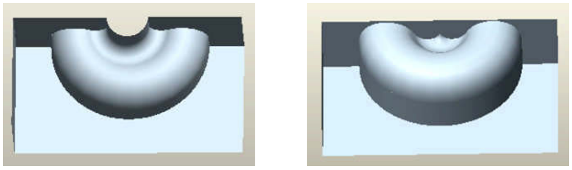
3 MODELING OF THE BOTTLE MOULD

Themodeling of the bottle mould halves happens in three sections: the top (Fig. 3 left) for which the sweep profile is parameterized as two circular arcs and two linear segments; the bottom (Fig. 3 right) for which the sweep profile is parameterized as two circular arcs and one linear segment; and the middle section which is characterized as one single arc (Fig. 4). These three sections are aligned and joined into the shape of a bottle mould half as shown in Figure5. The curvature of the middle section can be changed by altering the bend profile (Fig. 6).

The top and bottom sections of the bottle mould are created by a rotational sweep through an angle of 180 degrees around the symmetry axis of the bottle.The distance ‘d_2’ from the axis of revolution (Fig. 3 left) is equal to the radius of the neck of the bottle (Fig. 2).The distances ‘d_1’ and ‘a’ (Fig. 3) from the axis of revolution are matched with the dimensions of the middle section and the outer dimensions of the stock material(Fig. 4). The middle section of the bottle mould half (to be decorated with the tiling pattern) is modeled by sweeping a half-circle profile along the trajectories defined by the bend profileand suitably changing the size of the profile along the trajectories (Fig. 7).



(b)



(a)

Top section Bottom section

Fig. 3: (a) Parameterizedsweep profilesto create the top and bottom sections of the bottle mould half (b) 3-D models of the top and bottom sections.

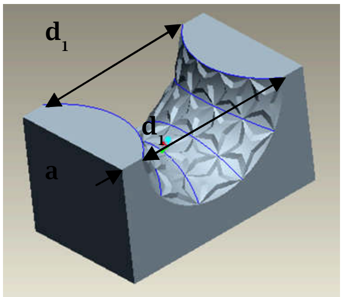


Fig. 4: The middle section of the bottle mouldhalf.

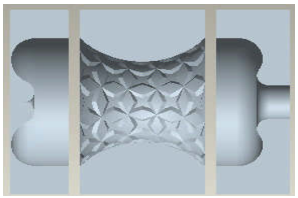


Fig. 5: Alignment of the bottom, middle and top sections.

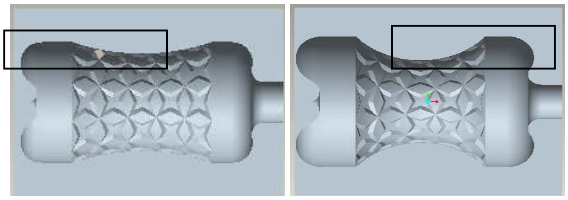


Fig. 6: Different curvaturesof the middle section,decorated with the samepattern.

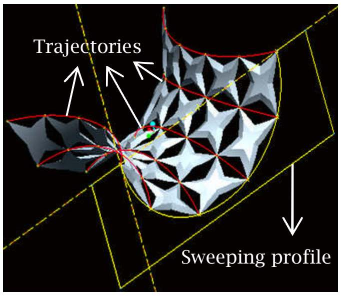


Fig. 7: Modeling of the middle section.

In order to apply a decorative bas-relief to the central portion of the bottle, the selected tiling pattern is bent toroidally (Fig.8). Firstly, the pattern is bent longitudinally according to a chosen bend profile (Fig. 9). This bend profile can take the form of a chain of entities such as splines, arcs, or lines. For our demonstration an arc defined by 3 points has been selected;its two endpoints lie at the ends of the decorative pattern and have to match up with the top and bottom sections of the bottle; the third point lieson the Z-axis and defines the radius and centre of bending curvature.

This curved longitudinal profile is then swept through an angle of 180 degrees to generate the decorated toroidal surface (Fig. 10). For modeling purposes the reference planes shown in Figure 11 are used. The neutral plane serves as a reference for the whole process. The sketching plane passing through the centroid of the pattern is used for sketching the bend profile. Two end planes parallel to the sketching plane, located at the boundary of the decorative pattern are use to control the amount of toroidal bending.

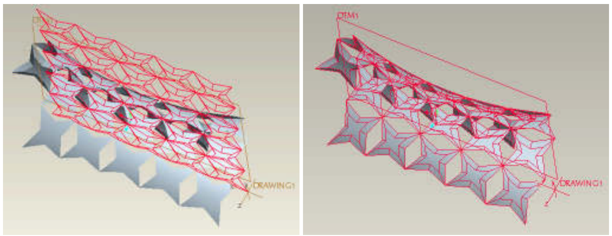


Fig. 8: Toroidally bending of the tiling pattern into the hyperbolic shape.

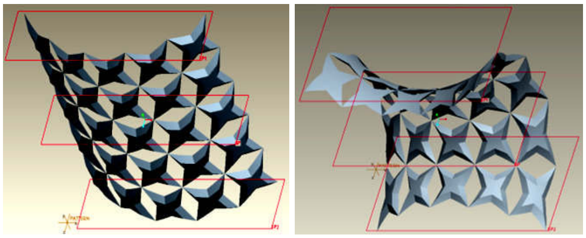


Fig. 9: Longitudinal bending along an arc. Fig. 10:Toroidalbending through180 degrees.

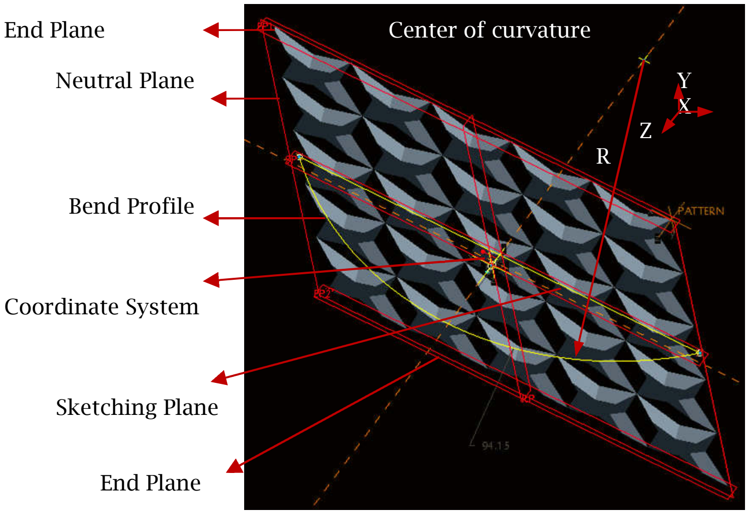


Fig. 11: Various reference planes.

4 DECORATIVE PATTERNS

Computer-aided geometric modeling techniques are used for producing a set of tiling elements as building blocks,which can then be arranging into patterned arrays [13]. The tiling elements are created by using a parameterized sketching approach. The figures are composed of simple 2-D entities (lines and arcs) passing through a number of points, which can be manipulated in 2D. These figures are thenextrudedinto the 3rd dimension guaranteeing appropriate depth and draft angle. Some of the figure templates and the resulting tiling elements are shown Figure 12. Multiple copies of the same or of different tiling elements are combined into an array with a specifiable number of rows and columns to create the entire modeling pattern (Fig. 13). This pattern is thenscaled to fit the middle section of the bottle to be decorated. Here is a listing of the parameters that define the tiling figures and their extrusion and mapping onto the middle section of the bottle:

1. Maximum number of points 'P' that define the tile figure. It may be nine, thirteen, or seventeen. The tile figure is confined to lie in a square. The four corner points and the central point of the square are fixed points. The other points are adjustable and allow to fine tune the figure (Fig. 14a).
2. Parameters'X' and 'Y' are defined as distances between fixed points and next/previous adjustablepoints in the horizontal and vertical directions, respectively. In Fig. 14a, distances 2-a, 4-b, 6-c and 8-d are specified by parameter Y, and distances 1-2, 2-3, 3-4, 4-5, 5-6, 6-7, 7-8, 8-1 are given by X. By adjusting those two parameters,many variants of a chosen tile figure can readily be generated.
3. Overall size of the tiling element'L', equal to the side of the bounding square (Fig. 14c).
4. Thickness of the element'T', equal to the depth of extrusion.This parameter must be chosen in conjunction with the draft angle (below) so that the thermoplastic (PET) material is not sheared off when it isblowninto the mould(Fig. 14c).
5. Draft angle 'δ' equal to the taper angle applied in the extrusion process(Fig. 14c).A sufficiently shallow angle guarantees easy removal of the thermoplastic bottle from the decorated mould.

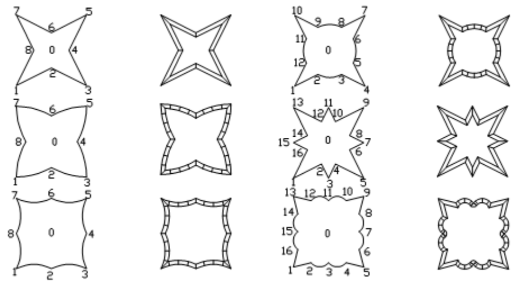


Fig. 12: Parameterized tiling figures.

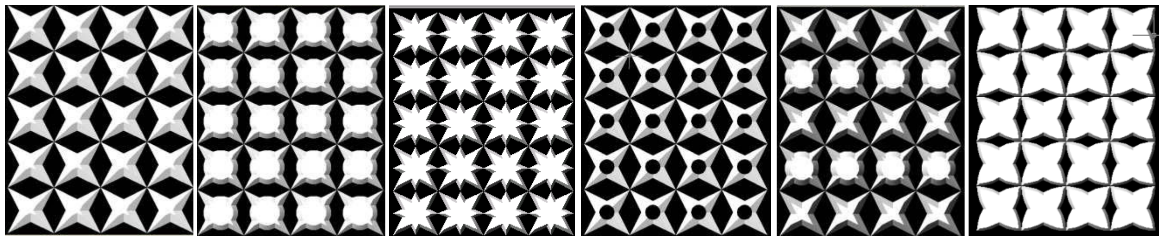
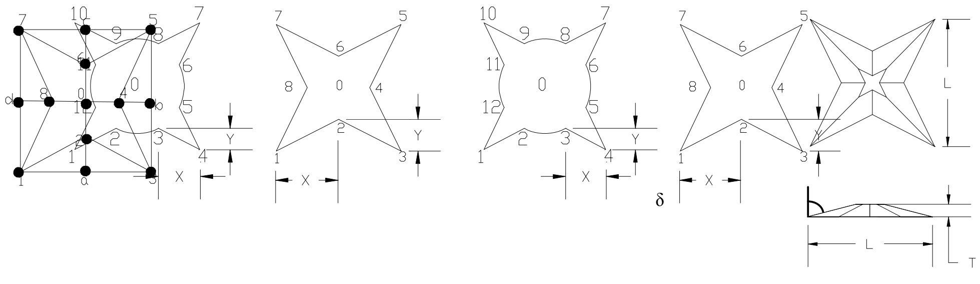


Fig. 13: Tiling patterns.

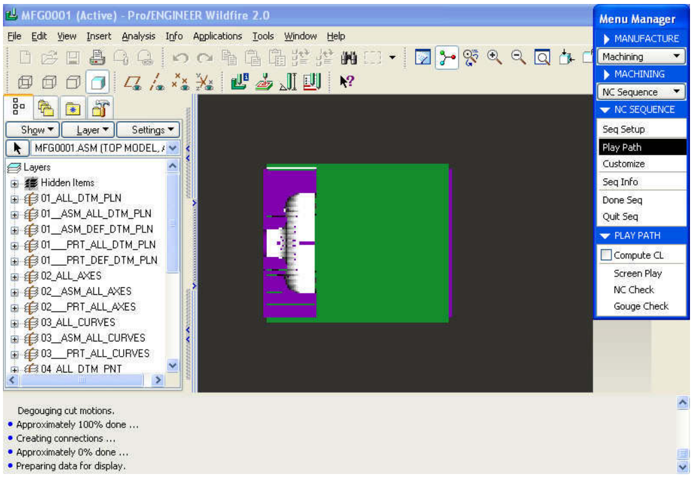


(a) (b) (c)

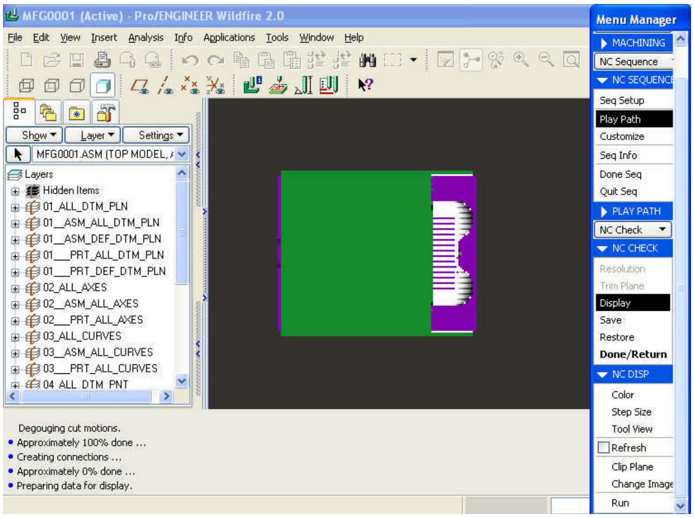
Fig. 14: Modeling parameters for tiling elements.

5 VALIDATION

The three sections of the bottle mould half have been simulated in a CAM (Pro/E Manufacturing) environment (Fig. 15),which provides NC programming capabilities for directly cutting and shaping mould parts using CNC milling. A prototype of the bottle mould half has also been fabricated ona Fused Deposition Modeling system (TITAN from Stratasys).The fabricated prototype is made of ABS (AcrylonitrileButadiene Styrene) plastic (Fig. 16).

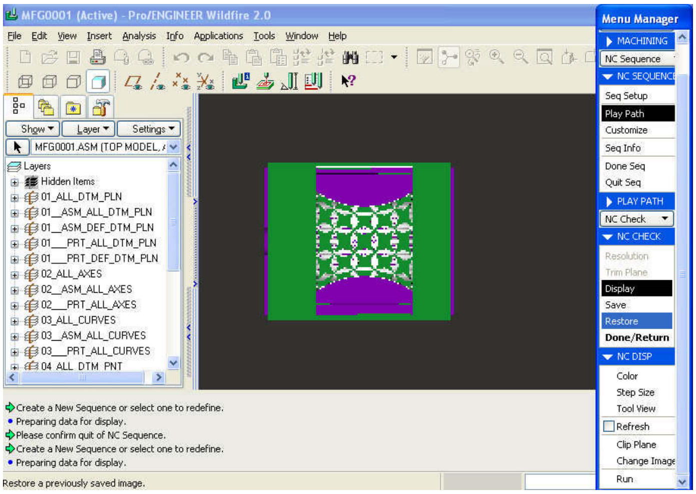


(a)

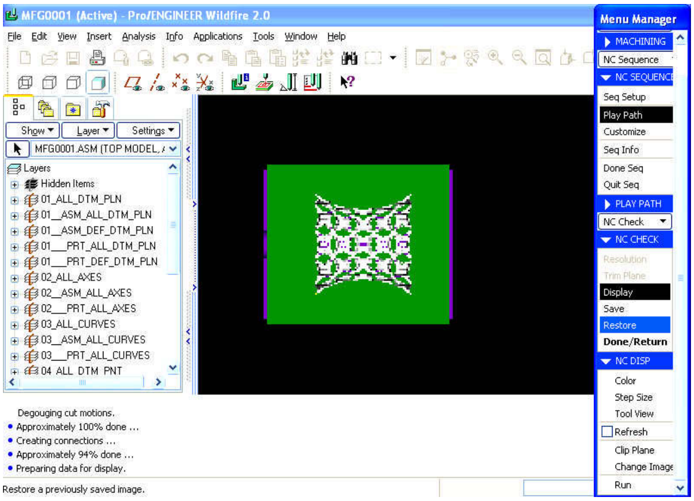


(b)

Fig. 15: Machining simulation of bottle mould: (a) top section, (b) bottom section.



(c)



(d)

Fig. 15: Machining simulation of bottle mould:(c) middle section, (d) tiling pattern.

Fig. 16: ABS plastic prototype of the bottle mouldhalf.

6 CONCLUDING REMARKS

This work describes a computer-aided toolforrapidly modeling blow-mouldsfor the fabrication ofdesigner PET bottles. A parameterized generator for decorative tiling patterns allows even a novice user to quickly create a design for a customized plastic bottle. An integrated modeling approach takes the designed decorative patterns and applies them to the CAD model for making the blow molds for manufacturing of waist bottles. The work demonstrates a feasible path by which every product could have its own dedicated bottle shape.

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