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Rapid prototyping in the manufacture of 3D printed molds for plastic blowing

Prototipado rápido en la fabricación de moldes impresos en 3D para soplado de plástico

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Abstract

In the Salvadoran industry, we can find entrepreneurs and microentrepreneurs who do not have the resources to make plastic bottles with stylized designs that differentiate them from other brands and products, which prevents them from escalating to other market segments or international markets, slows the growth of their business. One possible cause is that the manufacture of blow molds requires a very expensive initial investment. However, there are alternatives such as the manufacture of low-run molds, which have lower resolution and shorter life time, but, at the same time, offer as a benefit a lower manufacturing cost and, therefore, lower acquisition cost for the entrepreneur, opening in this way the opportunity to be able to produce stylized bottles at convenience. Among the various ways to manufacture low-run molds, there is the reverse engineering technique, which requires rapid prototyping equipment. This article describes the reverse engineering procedure to generate the mold for blowing. With the available design the necessary mold was printed and with this, the bottles were manufactured, which were scanned to verify with computer program their dimensions comparing them against the original mold file. Simultaneously, the containers were verified in the industrial metrology laboratory to validate the computer results, these results are presented in the document.

Keywords: Mold for blowing, 3D printing, rapid prototyping, plastic bottles.

Resumen

En la industria salvadoreña pueden encontrarse empresarios y microempresarios que no tienen los recursos para fabricar botellas de plástico con diseños estilizados que los diferencien de otras marcas y productos, lo que les impide escalar a otros segmentos de mercado o mercados internacionales, frenando el crecimiento de sus negocios. Una posible causa es que la fabricación de moldes de soplado requiere una inversión inicial muy costosa. Sin embargo, existen alternativas como la fabricación de moldes de bajo rendimiento, que tienen una resolución más baja y un tiempo de vida más corto, pero, al mismo tiempo, ofrecen como beneficio un menor costo de fabricación y, por lo tanto, un menor costo de adquisición para el empresario, posibilitando la producción de botellas estilizadas a conveniencia. Entre las diversas formas de fabricar moldes de bajo rendimiento está la técnica de ingeniería inversa, que requiere un equipo de creación rápida de prototipos. Este artículo describe el procedimiento de ingeniería inversa para generar el molde para soplado. Con el diseño disponible se imprimió el molde necesario y con esto se fabricaron las botellas, que se escanearon para verificar con el programa de computadora sus dimensiones comparándolas con el archivo original del molde. Simultáneamente, los contenedores se verificaron en el laboratorio de metrología industrial para validar los resultados de la computadora, estos resultados se presentan en el documento.

Palabras clave: molde para soplado, impresión 3D, creación rápida de prototipos, botellas de plástico.

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1. Introduction

The manufacturers of plastic containers and the Salvadoran entrepreneurs cannot acquire new steel and aluminum alloy molds for new products, since it requires a high initial investment that can only be amortized with the high production of products [1]. As an example, the metal versions of the bottle blow mold can cost from US$ 2,000 up to US$ 5,000, which regionally manufactured can be received between 30 and 60 days and manufactured in Europe or North America can be received from 90 to 150 days [2]. This implies that the micro, small and medium-sized Salvadoran companies with low profit margins cannot incorporate new products with differentiated plastic containers in their offer.

As alternative solution for molds, 3D printing becomes a "disruptive technological innovation driven by the flexibility it provides and the potentially favorable economics" [3]. Another applications of printed molds are used for hand-manufacturing composite parts [4]], manufacturing plastic parts [5], develop low-cost wax injection mold [6]. Whereas it alters traditional manufacturing approaches and promotes the expansion of rapid prototyping and digital manufacturing technologies.

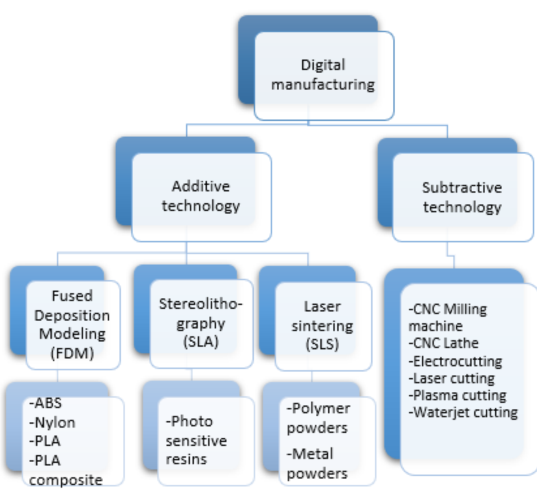

Figure 1. Digital manufacturing techniques.

Digital manufacturing technologies can be classified into additives such as 3D printing and subtractive as cutting equipment with CNC controls (computerized numerical control), as shown in Figure 1.

There are practices in the United States and Europe, where they use additive technologies such as SLA (Stereolithography) and SLS (Selective Laser Sintering) in the manufacture of molds by injection [7]. These technologies are high investment and useful in small-scale production.

To the knowledge of the authors the technique FDM (Fused Deposition Modeling) has been used little in the manufacture of molds. This work presents the manufacture of a mold by means of rapid prototyping and low investment FDM technology, with which containers with stylized designs are produced for each need.

2. Materials and Methods

Considering the modeling techniques, the mold generation methods could be classified in reverse engineering and CAD process (Computer Aided Design), represented in Figure 2 and described as 5 stages.

Applying reverse engineering, we scanned a container provided by the industry from which the mold was obtained for study.

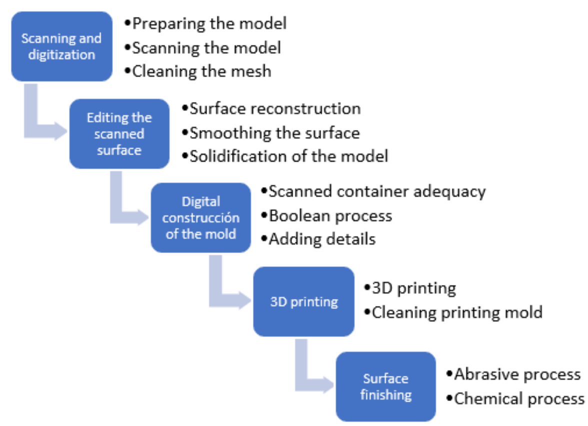

Figure 2. Stages of rapid prototyping applied.

In stage 1, the SmartScan R2-C2 scanning and scanning equipment with an accuracy of 0.01 mm and its Optocat 2015®software was used. The developer liquid is CANTESCO D101-A to attenuate the brightness and reflection of the surfaces to be scanned. The scanning procedure is in accordance with the user manual OPTOCAT version 2015R2 [8].

The temperature of the rapid prototyping room was kept in stable conditions (24 oC) and the entrance of light from outside was reduced less than 25% of the live image illuminated to avoid noise in the scanned images due to the light variations. The final cloud of points is saved in a file with STL format (Standard Triangle Language), to work then in other software.

During stage 2, the edition of the scanned surface was done with the treatment of the point cloud, using the CAD software GeoMagic Design X. The generated file was saved in STEP format (Standard for the Exchange of Product Data) which prevents the loss of design information.

For stage 3, the mold construction was carried out with Inventor software. Was incorporated block dimensions, alignment holes, thread, air exhaust holes, nozzle design.

Within stage 4, the material used in the 3D printing of the blow molds was ABS-plus (acrylonitrile styrene butadiene P430XL), the support material is SR-30XL (soluble support), the bottles material is PET (polyethylene terephthalate). Likewise, 3D printing process was done according with the user manual of the uPrint SE Plus printer, the software used is called CatalystEX and the system of elimination of support is the WaveWash equipment that works by means of ultrasonic washing [9]. The mold was used in the POLIFLEX company to manufacture 25 test bottles. With this first run the recommendations that make up stage 5 arise.

In stage 5 the surface finishes of the mold were made with automotive putty in the cavity where the container is formed. The manual sanding was carried out with sandpaper 1000 to improve the surface smoothness that facilitates the sliding of the PET during the blow.

Outside the reverse engineering process, the containers were scanned for comparison by software, and tests were performed in the industrial metrology laboratory to validate the software results.

3. Results and Discussion

In this section the results are presented in the order of blocks shown in Figure 2.

Stage 1. A cloud of points was obtained from the scan and digitization process, as shown in Figure 3. It was not necessary to scan the container's nozzle, since in the later stage of digital construction the nozzle design was incorporated. according to the blower machine. The possibility of change of nozzle in the mold occurs when planning to produce containers with machines that require preforms.

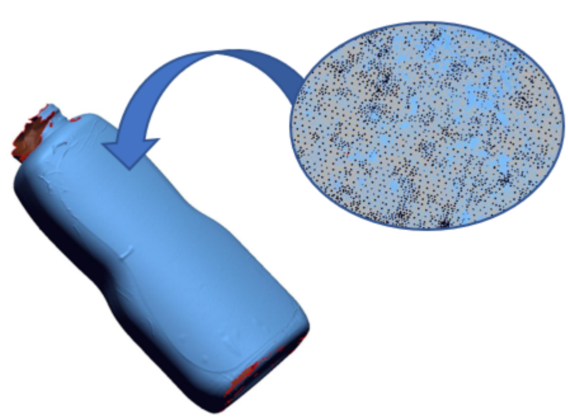

Figure 3. Nube de puntos del recipiente con formato STL, resultante del proceso de escaneado 3D y de escaneado y listo para ser procesado con software CAD.

Stage 2. The scanned surface edition consists of the set of operations to obtain a smoothed body, like cutting, merge, repair, smooth surfaces and borders. The STL file can be improved with any CAD software. The final bottle is shown in Figure 4, and can incorporate characteristic final details such as additional forms, areas for labeling, texts and logos in high and low relief, etc.

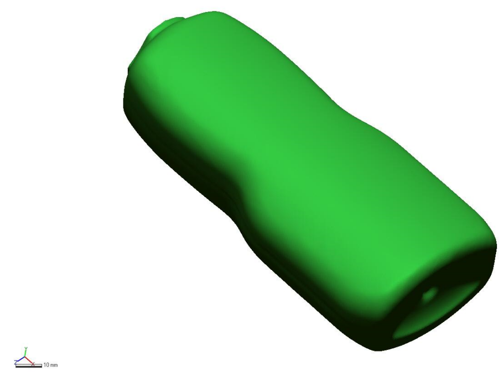

Figure 4. Bottle smoothed by computer and finished.

Stage 3. The digital construction of the mold consists in transforming the bottle from the previous stage (stage 2) to solid in the CAD. The solid body in the shape of a half bottle is joined by means of a process of cutting solid objects in the CAD software and later the details of the mold are added, for example, the fixing holes, threads, exhaust holes and nozzle spaces.

Some important considerations foreseen in the digitization of the mold, and that influence the quality of the products are:

- There were no defects in the overlapping of the container and mold block volumes.
- The thickness of the surfaces at the edges allowed to resist the loads received.
- The curvatures of the geometries and the surfaces are correct to reduce the stress concentration.
- The alignment of holes, pins, surfaces and edges were indicated to avoid unevenness in the surfaces of manufactured products [10].
- The tolerances of holes were correct so that both parts could be coupled during the production of containers with a sliding fit [11].
- The dimensions of the air exhaust were adequate so that no marks are seen in the manufactured containers.

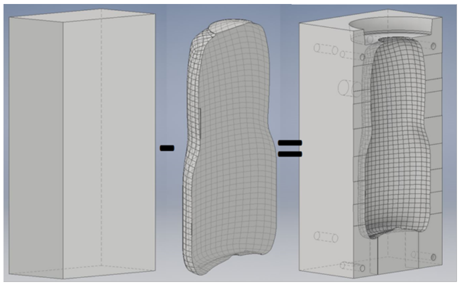

Figure 5. Sequence of processes for mold manufacturing: The solid body in the shape of a half bottle is joined by means of a process of cutting solid objects in the CAD software and later the details of the mold are added, for example, the fixing holes, vents and nozzle spaces.

The nozzle depends on the type of machine where the mold will be installed and the type of raw material. For example, the nozzle of the blow molding machine forms the external thread and uses granulated material, while the nozzle of the preform machine is smooth because it receives the preforms with its already manufactured thread. With this information a nozzle was drawn to the mold as shown in Figure 5.

The molds were designed with a removable bottom, which should be removed during the demolding of the container and installed during the closure of the mold. Its function is to evacuate the air during the blowing and form the bottom of the container to provide stability of it while remaining on flat horizontal surfaces.

The designed mold was analyzed by means of a computer with CAE Inventor software (Computer Aided Engineering), applying a pressure of 350 psi in the curved surfaces which is the blowing pressure for the manufacture of bottles. The results are shown in Figure 6, it is observed that could be an average deformation of 0.66 mm represented by the green area, and a maximum deformation of 1.026 mm at the bottom of the mold represented by the red area.

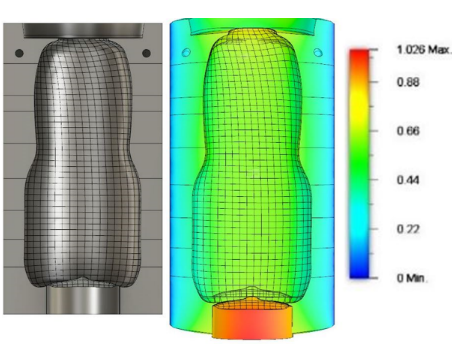

Figure 6. Critical points of the deformation of the mold, considering the points of concentration of efforts calculated by the software and shown in the color palette. The simulated charge pressure was 350 psi, analysis temperature 100 °C, and the units for deformation shown in the color scale in millimeters.

Stage 4. ABS was used as printing material, Figure 7. The height of the printing layers is 0.25 mm, shell thickness of outer surface 10 mm, infill density 100% in the wall, infill density in the middle 60%, top/bottom thickness solid layers 10 mm, with the uPrint SE plus equipment, which generates low resolution curved surfaces. This is difficult when you need smooth bottles, while for stylized designs with rough surfaces is an advantage. In our case the bottom of the mold was printed as part of one of the halves and although it showed some interference in the demolding, it affected 2 bottles of 25 so we considered that it had no negative effect during the manufacturing.

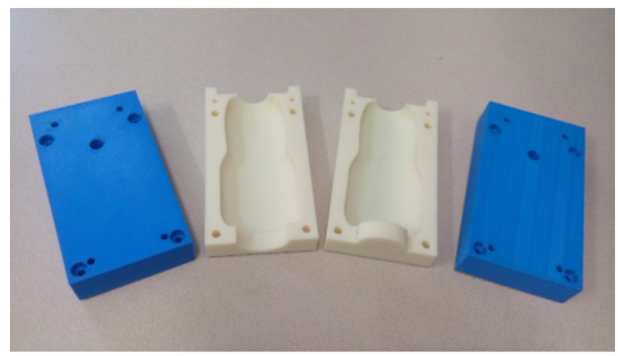

Figure 7. Blow molds for bottles printed in ABS.

The mold for blowing bottles is shown in Figure 7. The 3D printing mold includes ABS material and support material of suppliers in El Salvador, Table 1 shows 3D printing costs. The main cost is about materials and designer time, the cost of materials can be reduced when uses a open source 3D printer, and allows research about new 3D printing materials with better mechanical properties. The working time in CAD can be optimized practicing to improve skills.

Table 1. Cost of 3D printed molds, using prices of existing materials in the Salvadoran market

Cost of 3D printing mold		
Printing material (cubic centimeters)	552.48	
Support material (cubic centimeters)	227	
Printing material, cm^3 (unit cost)	$ 0.42	
Support material, cm^3 (unit cost)	$ 0.42	
Total cost printing material	$ 232.04	$ 232.04
Total cost support material	$ 95.34	$ 95.34
Cost of energy for printing	$ 0.86	
Amortization per hour	$ 2.65	
Printing time (hours)	12	
Power (kilowatts)	1.5	
Amortization during printing	$ 3.98	
Tax (IVA, El Salvador)	13%	
Total cost energy	$ 21.98	$ 21.98
Design/configuration (hours)	14	
Design/configuration (unit cost)	$ 10.00	
Total cost design/configuration	$ 140.00	$ 140.00
Total cost of 3D printing mold		$ 489.36

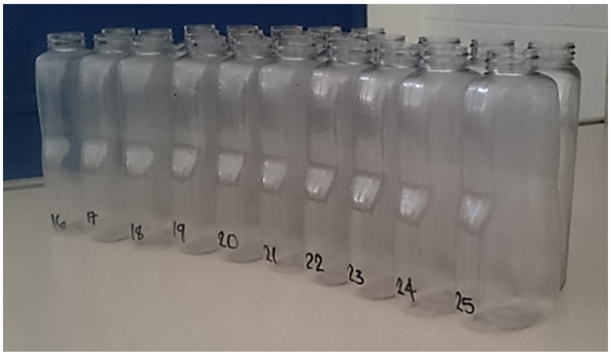

Figure 8. Plastic bottles made with the use of printed molds.

With printed mold, 25 containers were obtained in a production company, the mold was installed in one of its blowing machines and bottles were produced as shown in Figure 8. The mold and the bottles were verified with the help of the scanner, determining that they are in good dimensional conditions. It is considered that the surfaces of interest to evaluate are those that supported the pressure of the preforms during the blowing operation and the surfaces that supported the closing pressure of the machine.

The bottles were scanned and compared to the design of the mold in CAD format. Figure 9 shows the points of the digitally verified containers, based on the critical points resulting from the CAE Inventor analysis of the mold in Figure 6. In general terms, the dimensions of the containers are in the range of a tenth and a half millimeter above the average dimensions, and three tenths of a millimeter below the average.

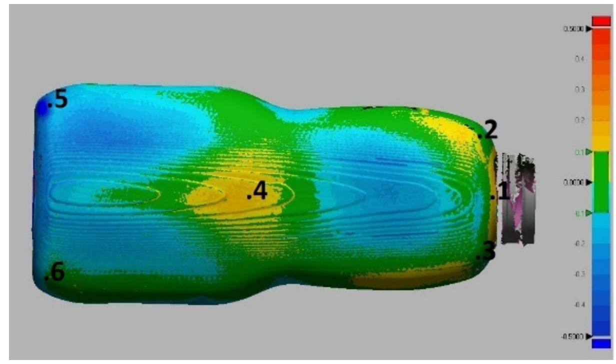

Figure 9. Digital verification of the dimensions of the containers produced with the printed mold together with its color palette.

The colors blue, light blue, green and yellow in Figure 9 denote minimum deviations of the scanned model with respect to the digital model, so it is verified that the manufactured bottles are kept in the ranges of +0.15 and -0.2 mm. The measurement results obtained with digital technique are shown in Table 2. Brown color denotes high positive/negative deviation and yellow color indicates low positive/negative deviation from the average dimensions, the dimensions are A=168.168 mm (high), B=61.130 mm (upper width), C=72.610 mm (lower width), D=41.518 mm (higher depth), E=43.049 (lower depth).

The containers were analyzed in the metrology laboratory to verify hermeticity, dimensions and weight [12]. The verification points and part of the equipment used are shown in Figure 10, and Table 3 shows an extract of the determined average and extreme values. Similarly, Table 4 presents an extract of the determined weights, indicating the extreme and average values. It is important to note that none bottle presents leaks after being tested with water.

Table 2. Results of the difference of measurements between the produced containers and the printed mold

Bottle number	Point 1	Point 2	Point 3	Point 4	Point 5	Point 6
1	0.0723	0.1644	0.0917	0.0881	-0.1216	0.0280
2	0.1439	0.1445	0.0832	0.0277	-0.0110	0.0636
3	0.1182	0.1125	0.0790	0.0624	-0.0580	0.0896
4	0.0175	0.1001	0.1109	0.0551	-0.0569	0.3939
5	0.0784	0.0383	0.0622	0.1062	-0.1231	0.0720
6	0.1094	0.0512	0.0196	0.1632	-0.2330	-0.0138
7	0.0704	0.1229	0.0094	0.1078	-0.2044	0.0223
8	0.0869	0.1268	0.0843	0.1458	-0.2595	-0.1917
9	0.1063	0.0729	0.0508	0.1260	-0.1681	-0.0795
10	0.1126	0.0972	0.0793	0.1312	-0.3859	-0.2118
11	0.1419	0.1103	0.1031	0.1056	-0.2024	-0.0397
12	0.1232	0.1455	0.1077	0.0906	-0.3409	-0.1720
13	0.1664	0.1377	0.1204	0.1109	-0.1183	-0.0979
14	0.1471	0.1288	0.0862	0.0909	-0.2086	-0.2159
15	0.1109	0.1257	0.0665	0.1428	-0.1994	-0.0293
16	0.1072	0.0673	0.0558	0.1033	-0.3444	-0.1224
17	0.1411	0.0258	0.0120	0.0973	-0.3811	-0.1013
18	0.1465	0.0938	-0.0205	0.1325	-0.3631	-0.0562
19	0.1019	0.0603	-0.0090	0.1041	-0.3061	-0.0247
20	0.1286	0.0966	0.0455	0.1397	-0.1682	-0.0201
21	0.1182	0.1136	-0.0018	0.1095	-0.2294	-0.0770
22	0.0677	0.1241	0.0256	0.1068	-0.1644	-0.0080
23	0.1159	0.1199	0.0478	0.1164	-0.1837	-0.0226
24	0.1147	0.1887	0.0476	0.1233	-0.1654	-0.0870
25	0.0905	0.1295	0.0803	0.0793	-0.2773	-0.0214

The verification team used 3D scanner and the GeoMagic software.

Table 3. Reference diagram for the dimensional analysis and execution of dimensional tests with the dimensions A high, B upper width, C lower width, D higher depth, E lower depth.

Results of the verification of the 25 bottles (mm)										
Dimension	**A**		**B**		**C**		**D**		**E**	
Vref	168.168		61.130		72.610		41.518		43.049	
ID of the bottle	**Average Value Vm**	**Error Vm - Vref**	**Average Value Vm**	**Error Vm - Vref**	**Average Value Vm**	**Error Vm - Vref**	**Average Value Vm**	**Error Vm - Vref**	**Average Value Vm**	**Error Vm - Vref**
1	168.160	0.008	61.073	**0.057**	73.038	-0.027	41.335	0.182	42.941	0.107
2	168.219	-0.051	61.075	0.056	73.003	0.007	41.250	0.267	42.907	**0.142**
3	168.148	0.020	61.098	0.032	72.986	0.024	41.167	**0.351**	42.979	0.069
4	168.173	-0.005	61.089	0.041	72.981	**0.029**	41.335	0.183	42.980	0.069
5	168.268	**-0.100**	61.082	0.049	72.993	0.017	41.315	0.203	42.978	0.070
12	168.162	0.006	61.137	-0.007	73.000	0.011	41.758	**-0.240**	42.990	0.059
15	168.148	0.020	61.131	-0.001	73.041	-0.030	41.527	-0.009	43.151	**-0.103**
18	168.139	0.029	61.173	-0.042	73.051	**-0.041**	41.604	-0.087	43.109	-0.060
24	168.044	**0.124**	61.182	**-0.052**	72.986	0.024	41.669	-0.152	43.120	-0.072

Table 4. Weight measurement results of the 25 containers

Results of the verification of the 25 bottles (g)		
Wref		283.538
ID of the bottle	**Average value Wm**	**Error Wm - Wref**
1	283.194	-0.0345
2	286.626	0.3087
5	283.559	0.0021
7	283.558	0.0020
8	283.555	0.0016
9	283.557	0.0018
22	283.289	-0.0249
23	283.252	-0.0287
24	283.236	-0.0302
25	283.202	-0.0336

The results in orange are the highest deviations above the average and in yellow the greater deviations below the average. The values Wm in grams.

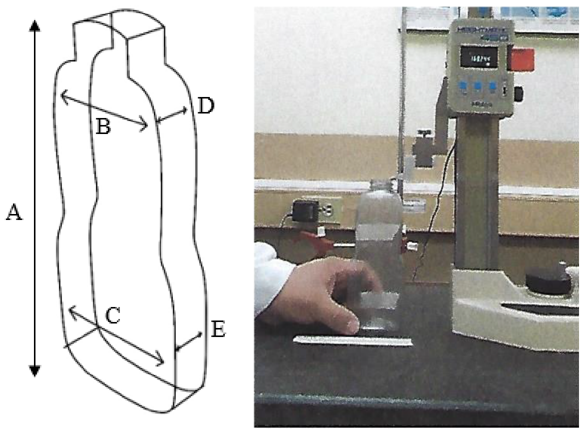

Figure 10. Reference diagram for the dimensional analysis and execution of dimensional tests with the dimensions A high, B upper width, C lower width, D higher depth, E lower depth.

Stage 5. To improve the surface finish, automotive putty was applied to the mold and smoothed with 1000 grade sandpaper, which achieved a smooth surface with roughness not noticeable to touch. This operation is variant to the normal prototyping procedure, where the models printed in 3D FDM are used without further processing. This artisanal process is recommended because it is inexpensive and does not take a long time or makes the mold more expensive, which transforms into a benefit for an SME with a low budget. The technical note of Hernández [13] refers to the level of roughness or smoothness effects on the flow of the parison during blowing because of friction against the surface of the mold. This fact may seem counterproductive, however, after observing the first containers, the surface texture can be a distinctive element for SMEs that can incorporate different designs in their packaging.

A useful result for SME users of the mold is the time elapsed from scanning until delivery of the finished and clean mold, which was 6 days. Delivery time is a positive factor when compared to mold delivery times at the regional level and outside the Central American region.

4. Conclusions

The work done shows that it is possible to apply reverse engineering to manufacture a 3D printed mold with FDM technique [14]. Reverse engineering resources are usually 3D scanning equipment, computers and scanning software, 3D printing equipment, measurement and verification equipment, among others.

The digitization process is replicable by institutions that have a high definition 3D scanner, where their product will be the digital file of the mold. The resulting file will be used to manufacture the mold in any institution that has a 3D printer, when resources are scarce, however, when the necessary resources are available, the file can be used to generate codes that are entered into computerized numerical control manufacturing equipment.

This work gives perspective to carry out research on superficial treatments of polymer molds for the increase of durability, study of the use of molds of low cadence in thermoforming processes, molding of biodegradable plastics with the use of printed molds, molds for reinforced composite materials. These results are precedents for those who have software and 3D printers can be incorporated in the productive field, providing design services and manufacturing of printed molds.

5. Acknowledgments

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