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Design of Mould Vacuum Thermoforming Machine using CNC Machine

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Abstract: For effective learning, the teaching and learning process needs to be efficient and equipped with the right resources. The absence of certain components can often lead to inefficiencies in the teaching and learning process. The study's goal was to use CNC machining to create a mold for a vacuum thermoforming machine. This innovation's objective was to use Inventor software to produce a mold design utilizing a CNC milling machine, with a size target of 250 mm x 300 mm x 180 mm. The findings indicate that the two thermoforming machine molds at the POLIMAS plastic production lab were impressed by the exploration. One mold is made of aluminum (AA6061) from a CNC milling machine, and the other is constructed of PLA (Polylactic acid) that is printed using a 3D printer. In the production of this thermoplastic container, the mold design and production process play an important role in making a good container. The temperature difference used to identify the appropriate temperature to use in the thermoforming process. The temperature used starts from 160ºc to 200ºc. The result is a suitable temperature between 165-170 °C. The project's outcome demonstrates how engineering expertise was used to improve the teaching and learning process. Both students and professors would benefit from a greater understanding of the thermoforming process.

Keywords: *Thermoforming, Mould, Rapid Prototyping, Inventor software*

1.0 Introduction

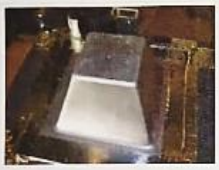
Plastic studies are the most important to educate as a student of plastic engineering and strong knowledge of plastic is vital. Consequently, earning must be holistic, comprising everywhere from physical teaching to memory spread of technology in various areas, as well as effective hands-on teaching and learning. As a result, as one of the key mechanisms of plastic manufacturing, we have determined to enhance the thermoforming process in terms of the molds. Moulds will be created utilizing different approaches and afterward tested to their specifications and put in use mainly for workshop usage by teaching and learning. Today's rapid prototype technologies are additive, deriving from the principle of dispersion and absorption. Using CAD, the objects to be prototyped are modeled in three dimensions (M. Jiménez, et *al.*, 2015). Then the model will be broken into a series of thin flat layers, which are then stacked to make an actual body. So, this is the only reason why plastic technology plays a huge role in many fields around the world.

Figure 1: Thermoforming Aluminum Mould

2.0 Literature Review

One pattern of the first type has been constructed aimed at assessing the geometrical accuracy of both the mould obtained by development and its behavior during the thermoforming process and the quality of the thermoformed final parts. The design was explored carefully and suited as well as possible to the main objective of the experiment and method of data analysis. The aluminum-magnesium alloy EN AW 5754 H32 is commonly used to manufacture mould in the food industry as it meets food and has good formability. The comparison of characteristics elements will be referred to in Table 1 below. The size was decided based on the ability to maximize its usage as if it were in real use. The type of aluminum used is AA6061 which is one of the most common aluminum types used to form a mould for thermoform by using a CNC milling machine (Botond-Antal Birton *et.al*., 2023).

Table 1: Criteria Comparison Table

Criteria	(1)	(2)	(3)	(4)	
Mold Design					
Mold Dimension	N/A		0.5 mm x 1.6 mm x 1.2 mm	8.5 mm x 3 mm x 35 mm	
Method of Production	- CNC Milling	- CNC Milling	- CNC Milling	- CNC Milling	- CNC (controlled tool) Milling
Parameters Tested	- Thermal Efficiency - SPIF	- Thickness - Depth - Pitch (mm)			- Individual layer thickness
Author	(Appermont et al., 2008)	(Rodriguez-Alabanda et al., 2018)	(Serrano-Mira et al., 2017)	(Buntinx et al., 2014)	

This production mode can also be made of aluminium or a more easily processed material, such as wood, fiberboard, or thermoset plastic. A prototype mould is meant to produce a few parts or to test design concepts. The focus of this innovation is on aluminium production moulds because it is the most used material in vacuum forming (Appermont *et. al.*, 2008). Aluminium is very well suited as mould material for several reasons: good wear resistance, good heat transfer characteristics, easy to machine, castable, and lightweight. Depending on the geometry of the mould not all techniques can typically be used. These advanced techniques can produce generic, freeform shapes using a standard, spherical-tipped, CNC-controlled tool. Selection of the correct sheet metal processing technique is an important step in the development of the mould (Rodriguez-Alabanda *et.al*., 2018).

3.0 Methodology

Within this project, we introduced the construction and design phases of a vacuum forming machine intended for educational use. The designed machine is functional like the machines used in industry, but the construction is considerably cheaper. With this equipment, students can more easily learn the vacuum forming method and use it to perform various laboratory exercises. In the manufacture of this thermoplastic container, the mold design and manufacturing process is an important part of making a good container. The temperature difference is used to identify the appropriate temperature to use in the thermoforming process. The temperature used starts from 160ºC to 200ºC.

i. Designing

The Autodesk Inventor software is used as a designing medium to sketch and design out the mould that was intended to be made as the final product. Here the exact measurements were put in as to what we wanted the final product to look like. The measurements included were length, breath and thickness of material.

ii. Simulation

For the simulation process, it is important as we need to apply it in different environments. This is how ever done through software again. CAD refers to the integration of Computer-aided design as shown in Figure 2.

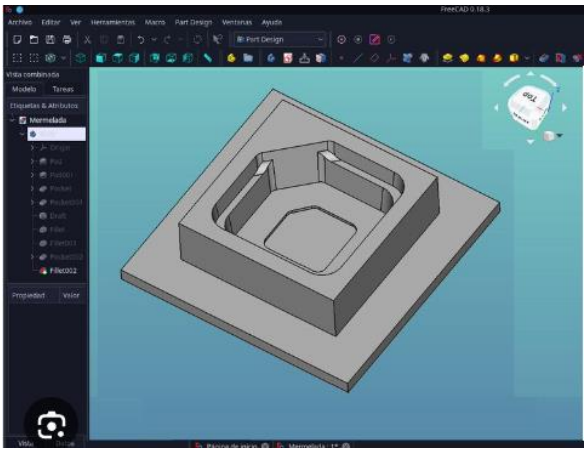


Figure 2 : Drawing using CAD software

CNC milling is a subtractive manufacturing process. It starts with attaching a piece of metal or plastic to a CNC milling machine. The CNC milling machine feeds the CAD model file into the CNC-readable G-

code program, which is used to program the CNC machine to quickly mill some of our raw material blocks.

4.0 Data Analysis and Findings

The data from this innovation were obtained after carrying out a specific method of data collecting. The parameters of the product namely temperature, pressure and time was the data collected. Although a methodology may typically fit into certain approaches, researchers may merge methodologies to fulfil their research objectives, culminating in multimethod and/or interdisciplinary methods as referred to Table 2.

Table 2 : Data Analysis

ADJ	TIME (SECONDS)						
	10	15	20	25	30	35	40
3	50°C	70°C	90°C	140°C	150°C	180°C	200°C
4	60°C	80°C	100°C	160°C	170°C	250°C	270°C
5	90°C	140°C	160°C	220°C	240°C	275°C	290°C
6	180°C	220°C	260°C	300°C	320°C	340°C	370°C
7	250°C	285°C	310°C	340°C	360°C	380°C	390°C
8	270°C	320°C	330°C	360°C	390°C	410°C	430°C
9	280°C	340°C	350°C	390°C	410°C	430°C	440°C
10	290°C	350°C	360°C	400°C	415°C	435°C	450°C
11	300 °C	360 °C	370 °C	410 °C	420 °C	440 °C	460 °C

Data analysis plays an important role in almost all researchers from small scale to big scale. It is found that it is important because of the after effect it contributes to. Additionally, recycled materials can be used as molds to ensure sustainability. Aluminum molds are useful for shallow drawing pieces and can expedite the fabrication process, despite their high cost. Data analysis aids in creating a more accurate set of data about the research been studied. The design process must be very consistent to ensure dimensional consistency. The use of digital controllers in the molding machine allows high precision in cycle times. Changing the time, a part stays in the mold directly affects the shrinkage of the part. The part must be kept in the mold until the resin reaches the specified temperature. Researchers use digital controls in our forming equipment and the ability to continuously monitor sheet temperature during the heating cycle to ensure consistent processing (Awari Mahesh Prakash *et.al.*, 2016; Mohd Hairol Mizzam Bin Haris *et.al.*, 2022).

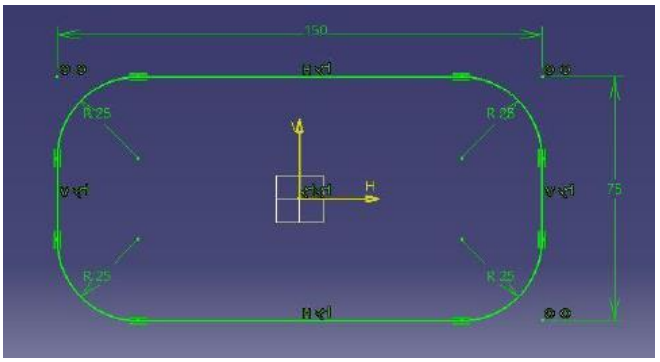


Figure 3 : Detail drawing

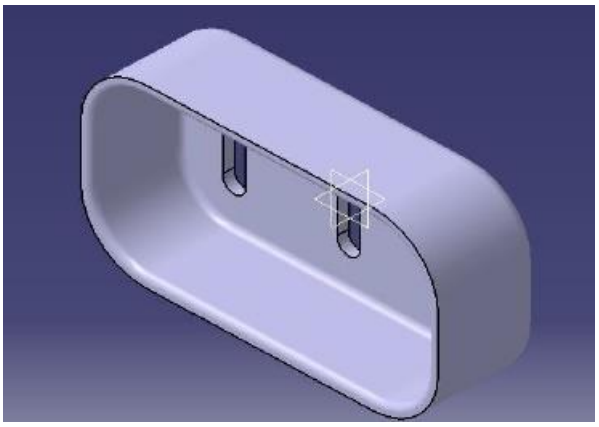


Figure 4: Product design

Having a plastic production thermoforming machine mold has become very useful and convenient for students and teachers. Not only that, but it also affected the quality of the teaching and learning experience for POLIMAS plastic technology students. However, this project was very mechanical, but it increased the plastic molding teaching and learning of both the lecturer and the students. Therefore, the purpose of this project is teaching and learning. Making mold from 3D printing and CNC milling opened additional learning opportunities and increased time for students to immerse themselves in plastic manufacturing processes (T. Stavroula, S. *et.al*., 2019; Mohd Hairol Mizzam Bin Haris *et.al.*, 2022). Figure 3 shows a detailed design of the product in question and Figure 4 shows the final design of the product.

Figure 5: Product design

5.0 Discussion

The mold structure of the container is successfully designed as shown above, but the shape of the lid is not perfect because the shape of the male mold is bad. The cover of the male mold must increase the train angle of the part by more than 5º because the thickness of the aluminum was large. Blisters occur because the coating mold has a flat surface. In conclusion, it can be stated that the cover structure of the thermoplastic container of this product must also be a female mold. In this experiment, the capacity and accuracy of pocket processing method validations were developed and approved. The acrylic plate was tested with the same parameter between two different conditioning strategies. The desired cutting time every half hour with an approximate parameter can be determined with the pocket milling software AutoCAD. A control air pressure was developed to determine the optimal pocket grinding time. With a certain cutting time series, the situation of the vacuum clamp that holds the acrylic sheet during processing can be predicted. Table 3 shows thermoforming troubleshooting for control that effect attempted.

Table 3: The thermoforming troubleshooting

Troubleshooting	Reason	Solution
Poor part detail	• Sheet temperature too low • Insufficient vacuum	• Increase the heater temperature before heat the sheet • Check the holes, increase number vacuum holes.
Ununiformed colour or surface	• Incorrect sheet temperature used	• Check the temperature correctly
Sheet tear while forming	• Temperature of the sheet too hot.	• Control the temperature in recommendation temperature.
Sheet webbing, wrinkling	• Sheet temperature too high • Webbing can also occur when a mould was too large or parts of the mould were too close together.	• Decrease heating temperature for the sheet
Dimples on mould side of part	• The vacuum holes was not less than plastic sheet thickness.	• Decrease the holes diameter

5.0 Conclusions

In general, it can be concluded that the work developed with the CNC milling machine was able to simultaneously and satisfactorily project the geometric deviations in the polymer vacuum thermoforming process, where there are goal conflicts between the quality parameters and the manufacturing variables using the laboratory infrastructure and with a small number of attempts. As explained above, the energy-saving technology of the plastic molding process can be divided into two areas. The first is a technique to reduce the electric power of heaters in plastic heating, and the second is a technique to improve the quality and performance of products, which increases the production volume of superior goods. The technological development of the latter in particular brings greater energy savings.

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