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Preparation of polypropylene thermoplastic container via thermoforming process

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Abstract. In this study, plastic containers made of polypropylene (PP) sheets were fabricated via vacuum thermoforming. Thermoforming is a process used in fabricating plastic parts by changing flat thermoplastic sheet to three dimensional shapes. In preparing these thermoplastic containers, the design and fabrication of mould were first done by using Catia V5 software and CNC milling machine, respectively. The thermoforming process was then performed at various temperatures ranging from 160^oC until 200^oC on the PP sheet to form the container. From the experiment, it can be suggested that the outcomes of final thermoplastic containers are significantly depends on temperature control during thermoforming process and also the vent holes design of the mould.

1. Introduction

The thermoplastic material type used in this project is Polypropylene (PP) the propylene used in many sector, among industries nowadays. Polypropylene is processed into film, rigid packaging, consumer products, technical parts and also textiles [3]. The properties of this (PP) material are economical material, good resistance to fatigue and also have a high melting point of temperature. The most important, polypropylene (PP) is recyclable and has number 5 as its identification. Polypropylene (PP) is useful for such diverse products as reusable plastic food containers, microwave and dishwasher safe plastic containers. Thermoforming is the process that used in industry for plastic part. Thermoforming process is a process of changing flat thermoplastic sheet to three dimensional shapes [5]. There are three types of thermoforming process which are vacuum forming, pressure forming and match die forming. Therefore, the design consideration for thermoplastic container is also important. The design of mould containers needs a practical design so that the container has a good quality, value and the part can be vacuum during thermoforming. The type of material used for mould also may affect the thermoforming process.



2. METHODOLOGY

2.1 The Design of the Mould

The container was designed by using Catia V5 software. The standard size for mould was less than 130mm width and 200mm length according to the size of the thermoforming plate mould. Draw ratio = depth of part/width of part. Draw ratio should be less than 2:1 for female moulds or 7:1 for male mould.

The mould design guidelines for parts need to consider through draft angle. The draft angle for male mould minimum was three degree, and for female mould draft angle minimum was one degree. The draft need to consider because of the thermal expansion of the plastic during thermoforming process. The coefficient of thermal expansion caused it shrink to the plastic part. The function of draft also to allows for better material distribution by opening up a corner area to allow clearance for a plug assist to push material or part. The drafted walls have less risk of plug hitting the sidewall. The larger the draft angle, the better in keeps the end use requirements of product.

2.2 Preparation of the Mould

The preparation of the mould start with the raw material, the raw material of aluminium block cut by using band saw for container and for container's. Figure 1 show the band saw using to cut the aluminium block. The aluminium block squaring manually by using milling machine before generates G-code. Figure 2 below shows the milling machine squared the aluminium block. The size for container size of squaring was 100mm x100mm x50mm and for their cover is 100mm x 100mm x 30mm.



Figure 1. The band saw cutting the aluminum block.

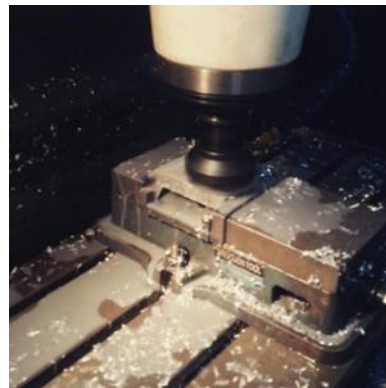


Figure 2. Squaring an aluminum block

The next process is machine the shape of mould. The CNC milling machine and some sort of CAD program used to cut out a solid block of aluminium. The Figure 3 shows the CNC milling machine the container's mould.

The mould need to drill the vent holes as the last process in the preparation of mould. The most important is the vent hole drilled to the mould, the diameter less than the thickness of the PP sheet.

Vent holes are drilled and placed in all the lower parts of the mould to provide for easy escape of trapped air. The Figure 4 shows the holes drilled to the mould. The diameter of drill tools used 1mm.

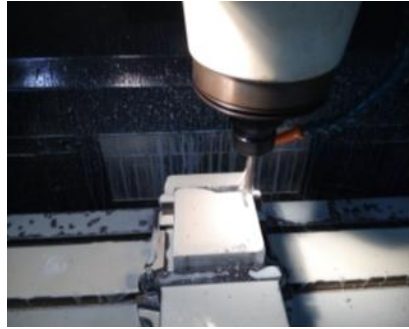


Figure 3. The aluminum block machine the container's mould

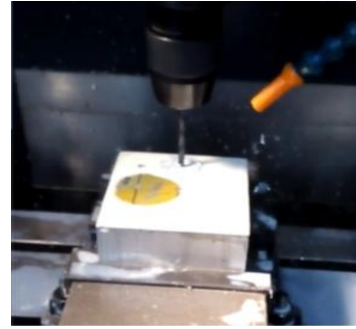


Figure 4. The drilling process of vent holes

2.3 Thermoforming Process

The thermoforming process type used in this project is a vacuum forming process as shown in Figure 5. A vacuum is formed between the mould cavity and the thermoplastic sheet. The basic processes for this thermoforming operation are, first the flat thermoplastic sheet is clamped. Second the sheet heated to its softening temperature (the temperature depends on the type of material used). Next, the force against the shape of mould form of vacuum pressure. The pressure used in this process is constant at 20 kPa. There are few stages involved in the vacuum forming process. Firstly, the mould was made from an aluminium material machine with the shape of container. Secondly, the mould shape placed in vacuum former. Thirdly, a sheet of polypropylene is clamped in the frame. Next, the polypropylene sheet heated and sealed to the container mould. Then, the vacuum is turned on and pumps out all the air. At this stage the shape of mould can be clearly seen through the plastic sheet. The plastic has cooled sufficiently the vacuum pumps switch off. After that, the plastic sheet removed from the vacuum part and the sheet has the shape as mould shape. Lastly, the excess plastic is trimmed so that the plastic container remains.



Figure 5. Thermoforming machine used

2.4 Parameter setting

The parameter setting is the guideline setting for thermoforming process that must be following to prevent shrinkage. The temperature of the thermoforming depends on the material used. For the polypropylene material, the recommendation temperature for PP formed is 165° C to 180°C. Sometimes, the temperature depend on the thickness of the plastic sheet itself, the machine used and also the type of mould. In this project, the experimental parameter of temperature set start form 160⁰C until 200⁰C. The temperature controlled start from 160°C, 165° C, 170° C, 175° C, 180° C, 185° C, 190° C, 195° C, and 200° C. The temperature sensor used to as the equipment to control temperature as shows in Figure 6. The vacuum pressure use is constant at 20psi. The vacuum pressure forces the sheet to forming to the mould and form the desired shape of the part. Then, the thermoformed part shape cooled.



Figure 6. The temperature sensor used

3. RESULT AND DISCUSSION

3.1The Design

The container successfully design by using Catia V5 software, in detail dimension for mould are in Figure4.1 below, the type of mould designed was female mould in square shape. Figure 7 and Figure 8 show the container design by Catia V5 software. The type of mould for container is cavity mould or female mould.

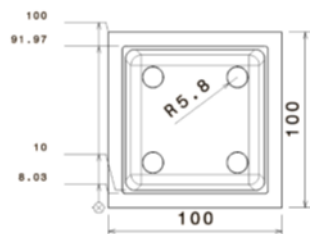


Figure 7. The details dimension

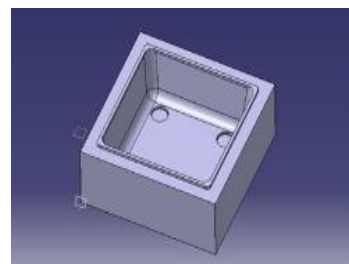


Figure 8. The mould designed by Catia V5 software

3.2 The Mould

The aluminium block machined using CNC milling machine and some short of g-cod program to follow the design of mould in Catia software. The Figure 9 showed the machine aluminium mould.

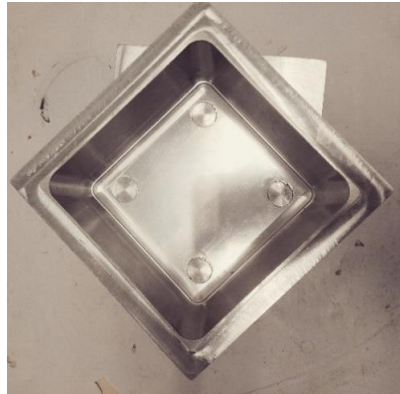


Figure 9. The aluminum mould

3.3 Thermoforming Process Result

This thermoforming process started with clamp a thermoplastic sheet in a frame. The plastic sheet is clamped in a frame as shown in Figure 10. Then, the PP sheet heated until it achieved sag point as shows in figure 11.

The heat time for PP with 1 millimeter (mm) thickness was recommend 50 seconds in theory but sometimes it depend on the machine thermoforming itself. In this experiment the time to reach sag point is 2minutes 20 seconds is the best.

Next, the constant vacuum pressure at 20 kPa is applied to the plastic to the mould so that the vacuum can be applied. Then the shape of the container form as shows in Figure 12.

After that the part of the container need to eject and the excess plastic is trimmed off. Figure 13 shows the excess plastic that need to trim off after ejection process. Lastly, the thermoplastic container part is successfully form by thermoforming process as shows in Figure 14.

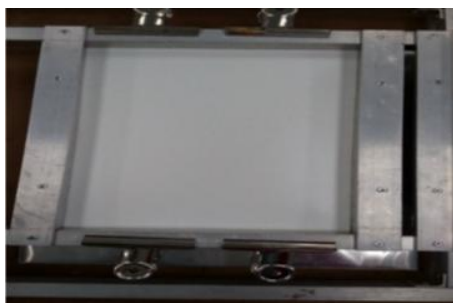


Figure 10. The pp sheet is clamped in the frame



Figure 11. The plastic sheet at sag point

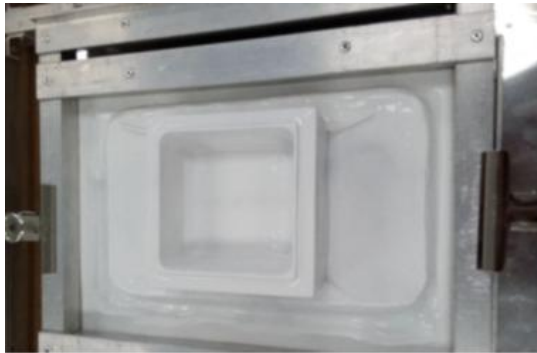


Figure 12. The PP sheet form by applied vacuum



Figure 13. The excess plastic trimmed off



Figure 14. The container







3.4 The Result for Temperature Parameters Used

The temperature used to heat PP sheet at 160⁰c to 200⁰c to identify which temperature is the best in this experiment. In this range temperature, the result shown the temperature in range 165⁰c to

175⁰c is good temperature compare to other temperature during the thermoforming process but 175⁰c is the perfect surface. Table 1 below shows the result of container with different temperature used.

The data was record during thermoforming process shows in Table 2. Based on the table below it shows that the increasing the value of temperature, the time taken become longer and the plastic part closed to melting molten plastic which it cannot form good shape of the container.

Table 1. The effect of different temperature used

TEMPERATURE USED	RESULT	DESCRIPTION
160 ^o c		At this temperature the container shape follow the mould design but the bottom thickness of the container not uniform.
165 ^o c		The container form is good.
170 ^o c		At this temperature of PP sheet heating form good surface of container.
175 ^o c		This temperature is better than 170 ^o c and 165 ^o c
180 ^o c		180 ^o c cannot be recommended as temperature of forming because at this point the PP sheet started wrinkle at the side wall part.
185 ^o c		This temperature produced bad surface of container.

190°c



The plastic container wrinkle at the top side wall of the container.

195°c



The wrinkle increases at high temperature.

200°c



Too hot temperature at 200⁰C, causes the result of container fail to forming perfectly at this temperature.

Table 2. The data record during thermoforming process

No	Room Temperature	Temperature of Mould	Temperature of PP Sheet	Time Taken For PP Sheet	Vacuum Pressure Applied (Kpa)
1	27 ° c	40° c	160° c	1min 40 second	20
2	27 ° c	40° c	165° c	2 min	20
3	27 ° c	40° c	170° c	2 min	20
4	27 ° c	40° c	175° c	2min 20 second	20
5	27 ° c	40° c	180° c	2 min 30 second	20
6	27 ° c	40° c	185° c	2 min 50 second	20
7	27 ° c	40° c	190° c	3 min 30 second	20
8	27 ° c	40° c	195° c	3min 50 second	20
9	27 ° c	40° c	200° c	4 min	20

4. DISCUSSION

4.1 Mould Effect

This grid ink was placed on the top of the plastic sheet to see the stretch mark area and the thickness of plastic part form. Figure 15 shows the stretch mark for temperature 170⁰c outside mould wall area which has a lower thickness than the bottom area. This caused by the hot sheet contacts with the outside wall area of the mould at first step in the female mould and consequently the sheet sticks to the mould.

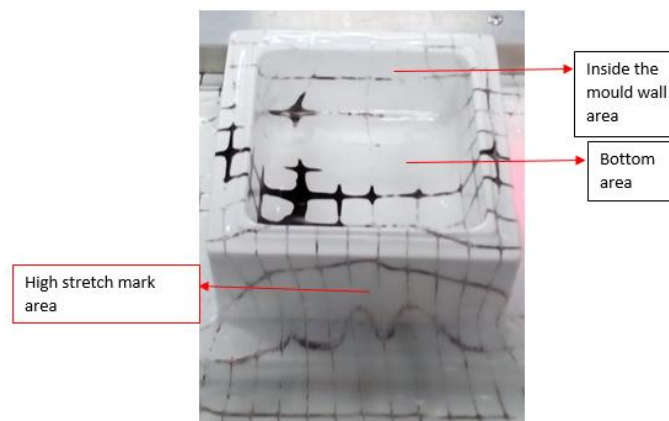


Figure 15. The stretch mark (170⁰c)

The stretch mark area shows in Figure 16 below is for 200⁰c heating temperature. This temperature is too hot and causes the stretch area tears.



Figure 16. The stretch mark (200⁰c)

This discussion proved based on the previous research about Numerical and Experimental Analysis of HIPS Sheets in Thermoforming Process by author Mohammad Ghobadnam Peiman Mosaddegh & Masood Rezaei Rejani & Hosein Amirabadi & Abbas Ghaei. Published 13 September 2014 [10]

5.0 CONCLUSION

This research study is basically an application of thermoforming process where the main study of plastic process in industry nowadays, and to identify the main advantage of thermoforming process compare to other plastic part process in industry today. The main of this experiment also, to test the process of thermoforming process based the mould design for the container.

This experiment also to identify the suitable temperature and time range used for heating temperature Polypropylene (PP) sheet during process of thermoforming.

Based on these experiments that were done, it can be concluded that the experiment successfully fulfils the first objective that was to design and fabricate the mould. The female mould was the best design for vacuum forming process.

There are some PP sheets not form perfectly during the process because the temperature not suitable and the pressure was released on two earlier causes the plastic soul before it form. This experiment proves that the different temperature used during these thermoforming will get different result either on the surface uniformity or the thickness. Based on the result, the suitable parameter temperature used for this thermoplastic PP container is in range 165⁰c to 175⁰c. As for the conclusion, the factors that affect thermoforming process is the mould design, vent holes and heating temperature for thermoplastic.

6.0 REFERENCES

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