

A Study of Applications of 3D printing technology and potential applications in the plastic thermoforming industry

Nkosiathi Z Nkomo^{1*}, Jephias Gwamuri², Nqobizitha R Sibanda³,
Londiwe C Nkiwane⁴

^{1,3,4}*Department of Fibre and Polymer Materials Engineering, National University of Science and Technology,
P.O Box AC 939, Ascot, Bulawayo, Zimbabwe*

²*Department of Applied Physics, National University of Science and Technology, P.O Box AC 939, Ascot,
Bulawayo, Zimbabwe*

*Corresponding author: Nkosiathi Z Nkomo

Abstract: In this study applications and potential uses of 3D printing in the plastic thermoforming industry are studied. Additive manufacturing has revolutionized the modern manufacturing process and engineering design process. Thermoforming is widely used in plastic manufacturing industries to produce a range of polymer products such as products in the packaging industry. Thermoforming moulds are mostly produced using conventional mould building technologies and are made of steel. These mould are robust but only suitable for mass production and take some time to fabricate. 3D printing can find use in thermoforming industry in creating moulds this can produce the moulds quickly, economically as well as prototyping of the packaging material. 3D printing allows ease of production of personalised packaging. With 3D printing the structural design of the package could be customised on request. As more sustainable bioplastic filaments are innovated, the adoption of 3D printing in packaging manufacturing may help save the environment. 3D printing works well with Acrylonitrile Butadiene Styrene (ABS) and polypropylene. This paper looks at the different applications of 3D printing in the plastics thermoforming industry and looks at the viability of the use of this technology as well as the advantages in relation to conventional production technologies.

Keywords: 3D printing, packaging, plastic thermoforming, prototyping

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I. INTRODUCTION

Three dimensional (3D) printing also known as additive manufacturing is a process of making solid objects from a digital file. This creation of the 3D printed object is accomplished by an additive process [1]. 3D printing employs an additive manufacturing process whereby products are built on a layer by layer basis through a series of cross sectional slices [2]. 3D printing enables the low-cost, bottom-up fabrication of objects with complex geometries that are difficult to produce by traditional fabrication methods [3]. The emergence of 3D printing shortens the cycle of design and development for thermoformed products. The application of 3D printing increases the efficiency and promotes product development [4]. Since 1984, when the first 3D printer was designed and realised by Charles W. Hull from 3D Systems Corp [4].

II. THERMOFORMING

Thermoforming is a reshaping process in which a flat thermoplastic sheet is heated and shaped into moulded parts. The extruded sheet is heated to softening temperature clamped around its edge and formed to the required shape by mechanical stretching and applying pressure against a mould with the desired shape [5]. The softening temperature depends on the thermoplastic material properties.

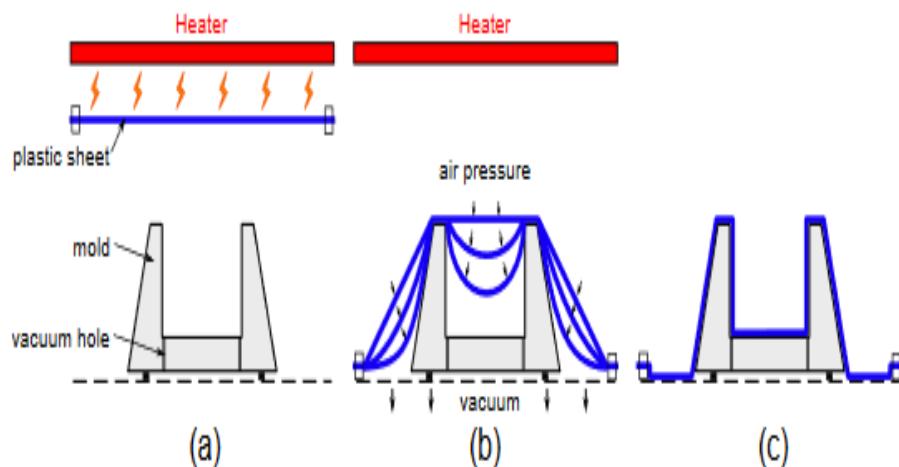


Fig 1.0 Typical vacuum thermoforming process. a) A plastic sheet is heated until soft enough for forming b) then it is loaded to the mould; upon contact with the mould it begins to deform. The air below is vacuumed, the atmospheric pressure forces the plastic sheet to conform to the mould shape c) after cooling down, the plastic is hardened into the new shape [6].

Thermoforming is mainly used in the packaging industry. However it is not limited to small products; hot tubs and refrigerator door panels are two examples of relatively large thermoformed parts [7]. In the thermoforming industry it is necessary to use chillers for cooling the chains transporting the plastic sheet.



Fig 2.0Vacuum thermoforming machine

III. CONVECTIONAL MOULD DESIGN FOR THERMOFORMING

The typical thermoforming mould design and manufacturing process used by most manufacturing companies are done manually and rely heavily on craftsmanship. A thermoforming master model is formed first the geometry of the model is often refined region by region since it is difficult to adjust the entire shape of the model manually at one time. From this master model if the customer is satisfied with it then a metal mould can be made for mass production. The making of the mould has drawbacks in that it relies very much on the skill of the mould maker and the modelling and finishing processes are laborious and time consuming. This makes this process significantly expensive [8]. The mould used needs to have four basic functional features which are packaging, draw ratio, demoulding and strengthening. The basic function of the thermoforming mould is to hold secure and protect a packed part.



Fig 3.0Plastic thermoforming mould for biscuits skillets

The drawing process causes an increase of surface area but decrease of sheet thickness [9]. Thermoforming features with low draw ratios are easier to form. This explains why thermoforming mould makes chamfer sharp edges, add fillets to acute corners and fill up deep depressions to avoid the formation of high draw ratio features. The mould used must also allow easy demoulding. This is done by allowing the side walls of the mould to taper outwards. Fig 4.0 shows the main features of a thermoforming mould.

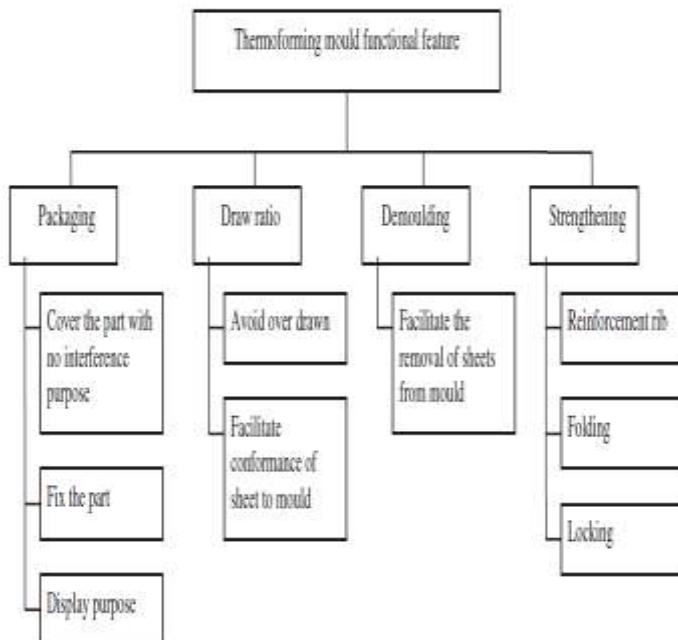


Fig 4.0Classification of functional feature of thermoforming mould [8]

IV. DIMENSIONAL (3D) PRINTING PROCESS

The 3D printing process consists of two stages:

- The direct transfer from software data to printed structures,
- Repeatedly positioning the print head in all three directions in space in order to print layer by layer [10].

There are three main types of 3D printing which include stereo lithography (SLA), selective laser sintering (SLS) or fused deposition modelling (FDM).The principle of fused deposition modelling (FDM) works by melting a thermoplastic filament in an extruder nozzle and deposition of the thermoplastic in layers on a bed.

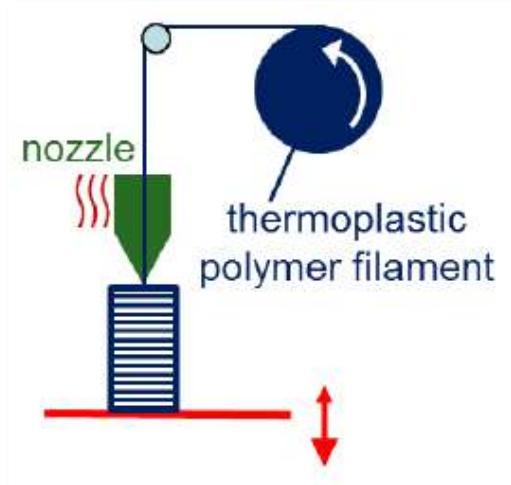


Fig 5.0Schematic depiction of fused deposition modelling (FDM) technology [11]

Since 2009, the number of low cost 3D printers from both major and start-up companies has greatly increased with many now using the now off-patent FDM technology [12]. An example of such a printer is the Athena 3D printer shown in Fig 6.0 which has been used to prototype some basic packaging products in this study.



Fig 6.0 Athena 3D printer

The process of 3D printing involves the following key 4 steps:

1. **CAD Model creation:** The object to be printed is modelled using a Computer-Aided Design (CAD) software package. The designer can use a pre-existing CAD file from various open sources that are available online.
2. **Conversion to STL Format:** the various CAD packages use a number of different algorithms to represent solid objects. To establish consistency, the STL stereo lithography format has been adopted as the standard of the rapid prototyping industry. The second step, therefore is to convert the CAD file into STL, format.
3. **Layer by Layer Construction:** using one of several techniques the 3D printer builds layer by layer the object.
4. **Clean and Finish:** the final step is post processing this involves removing the printed object from the print bed and if necessary carrying out curing on the object. Some objects require minor cleaning and surface treatment.

V. RAW MATERIALS USED IN 3D PRINTING AND THERMOFORMING INDUSTRY

Similar thermoplastic raw materials are used in the plastic thermoforming industry and in 3D printing. Polyactic Acid (PLA) is one type of thermoplastic filament used which is a biodegradable thermoplastic aliphatic polyester derived from renewable resources such as corn starch, tapioca roots, chips or sugarcane [13]. Fig 7 shows the skeletal formula for PLA.

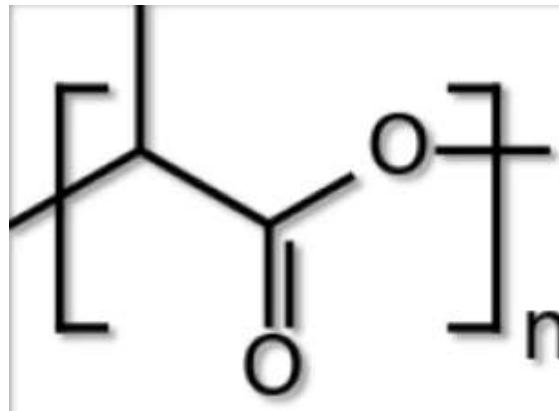


Fig 7.0 Skeletal formula for PLA

Another commonly used filament is ABS which is also commonly in the food packaging industry. ABS is used to make skillets for packaging biscuits as well as plastic cups.



Fig 8.0 Skillets and cups used in food industry

VI. USE OF 3D PRINTING IN THERMOFORMING INDUSTRY

A major advantage of 3D printing is a firm's ability to quickly and cost effectively supply low demand parts without the risk of carrying unsold finished goods inventory [2]. This can be done without the need for creation of extrusion process to produce the required plastic sheet with the required density and specifications.

Use of 3D printing can create personalised packaging. With 3D printing the structural design could be customised on request without a need for changing the mould or creating another mould. The packaging of a product can be just as important as the product itself when it comes to accumulating sales this is one of the reasons why prototyping is so important. It helps to create a prototype to show customers as well as to test the product for suitability for use before creating an expensive mould for the product.

Traditional production methods are subtractive production methods which result in huge material losses, while 3D printing is an additive production method [14]. However when using 3D printing technology, only the amount of raw material necessary is used in the fabrication of the intended product. This results in a lesser carbon footprint and has a great positive impact on the environment [15]. Less recycling is needed with 3D printing as it is more exact in the formation of the product.

For lower production volumes, 3D printing can reduce the time and expenses associated with conventional machining processes. It is possible to produce accurate moulds with an automated, unattended process and eliminate the need for setup and operating of CNC machines.

Advantages of 3D printing in comparison to other technologies include:

- No need for costly tools, moulds, or punches
- No scrap milling or sanding requirements
- Automated manufacturing
- Use of readily available supplies
- Ability to recycle waste material
- Minimal inventory risk as there is no unsold finished goods inventory
- Improved working capital management as goods are paid before being manufactured
- Ability to easily share designs and outsource manufacturing
- Speed and ease of designing and modifying products

Fused Deposition modelling is the most common 3D technology employed for creating 3D printed moulds for vacuum forming. It allows printing in various fill densities and results in a uniform vacuum to be drawn throughout the tool. In addition FDM 3D printing machines are capable of printing moulds in a variety of durable, heat resistant plastic that prolong the life of the mould [16].

An example of a 3D printed mould is such as the one used in the CREOS encasing which is a PETG plastic shell that was vacuum formed using a 3D printed FDM tool. Fig 9.0 shows the mould that was used. CREOS is a 3D printed action figure with detachable arms and legs. The hat is created in Nylon12 on an SLS machine and dyed yellow. The callipers were printed in real ABS thermoplastics.

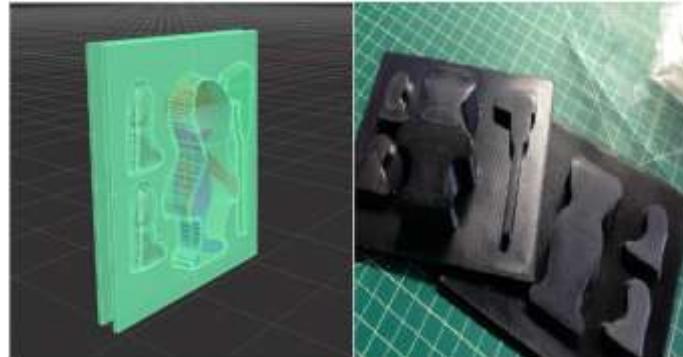


Fig 9.0Mould used for the encasing of the CREOS action figure [16]



Fig 10.0CREOS 3D printed action figure in it encasing [16]

VII. CONCLUSION

The use of 3D printing technology plays a role in the plastic thermoforming industry in producing the products as it uses similar thermoplastic materials such as ABS and HIPE which are used in the traditional plastic thermoforming industry. 3D printing has advantage of ease of customisation, minimum wastage during the production of the products as it works by additional manufacturing and only the required material is deposited. However this technology is still limited due to its slow speed compared with vacuum thermoforming. 3D printing is having growing use in the fabrication of tool used in thermoforming such as the moulds. Fast and efficient mould generation can be done using 3D printing. This technology is growing and in the years ahead it is expected to grow in its capacity usage.

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