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DESIGN AND DEVELOPMENT OF VACUUM FORMING MACHINE FOR THERMOPLASTIC MATERIAL

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Abstract: Vacuum-forming or thermoforming is one of the most common methods for processing plastic materials. Vacuum-formed products are prevalent in our daily lives. The process involves heating a plastic sheet until soft and then draping it over a mold. A vacuum is applied sucking the sheet onto the mold. The sheet is then removed from the mold. In its advanced form, the vacuum-forming process utilizes sophisticated pneumatic, hydraulic and heat controls thus enabling higher production speeds and more detailed vacuum-formed applications. An improved vacuum forming process for forming a deep drawn plastic article with a flange in an area of high forming stresses wherein a mold mounted on a base forms the shape of the article. A sheet of hot plastic material is placed over the mold and a vacuum is drawn to form the plastic sheet into the shape of the mold to form the article. The improvement is forming a character in the mold portion that forms the flange in the area of the high forming stress, said character having dimensions such that properly heated plastic sheet material will be imprinted with a predetermined clarity during the molding operation. A heated sheet of plastic material is placed over the mold and a vacuum is drawn to draw the plastic material around the mold including the mold portion that forms the flange in an area of high forming stresses. The plastic material is then solidified and removed from the mold. The flange is visually inspected to determine if the imprinted character has the predetermined clarity. If it does, the plastic material was heated to the proper temperature for the molding operation. If it does not, it means that the plastic material was not heated to the proper temperature and the area will be subjected to stress cracking and therefore the article is defective and should be discarded.

Keywords: Vacuum, Forming, Thermoplastics, Recrystallization temperature, Standoff distance, radiant heater.

1 INTRODUCTION

Forming processes are particular manufacturing processes which make use of suitable stresses (like compression, tension, shear or combined stresses) to cause plastic deformation of the materials to produce required shapes. During forming processes no material is removed, i.e. they are deformed and displaced.

1.1 THERMOFORMING PROCESS

Thermoforming is one of the oldest and most common methods of processing plastic materials. Thermoformed plastic products are all around us and play a major part in our daily lives. It is a very versatile process used to manufacture a wide range of products from simple packaging trays to high impact aircraft cockpit covers. It is also used extensively to make design prototypes of products to be produced by other processes. The process, however, is basically the same in each case. In its simplest form thermoforming is the heating of a plastic sheet which is then draped over a mould whilst a vacuum is applied. The moulding is then allowed to cool before it is ejected from the mould using a reverse pressure facility. Thermoforming covers all processes which involve heat to shape polymers. However, in this manual we will concentrate specifically on the 'vacuum forming process' which applies to the range of machines supply. Vacuum forming has generally been promoted as a 'dark art' and best left to companies with sophisticated processing equipment who are able to supply the facility and service[3]. However with their range of compact, easy to use machines have, over the years, endeavoured to introduce vacuum forming to the 'masses' and it is some testament that there are now over six thousand machines worldwide, many supplied to those looking to start vacuum forming for the first time. In this manual we hope to provide an insight into this adaptable process.

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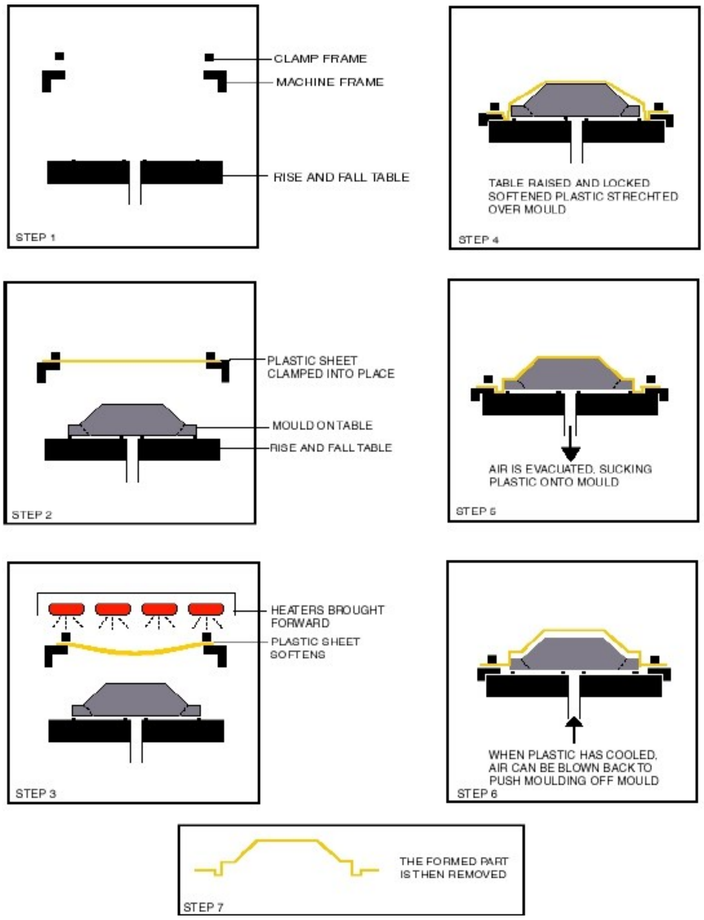

Fig. 1.1 Vacuum Forming process

1.2. TYPES OF THERMOPLASTIC MATERIALS

Polymers are made up of molecules which in turn are made up of atoms. These atoms have many different combinations which all have different properties and contain a wide range of additives to give each material its own characteristics. There is constant research being carried out to develop new materials suited to an ever increasing range of applications. Later in this section we have provided a breakdown of the more common materials used for thermoforming, their characteristics and the applications to which they are most suited.

Thermoplastics are split into two different groups – amorphous and crystalline[1]. Crystalline thermoplastics contain an ordered manner of molecules and amorphous contain a random arrangement. Generally speaking amorphous materials, e.g. Polystyrene and ABS are easier to vacuum form as they do not have such a critical forming temperature. When heat is applied amorphous materials becomes soft and pliable – when it reaches this state it is known as its Glass Transition Temperature (Tg). If heated to a higher temperature it reaches a Viscous state (Tv)[2]. The changes occur over a range of temperatures and enable the operator to have a fairly wide forming range. Semi-crystaline and crystaline materials, e.g. Polyethylene and Polypropylene have a far more critical forming temperature as they go rapidly from the Tg state to Tv a change known as the Melt Transition Temperature (Tm). When using crystalline materials is imperative that accurate temperature control is used to monitor the heating process.

1.2.1 Acrylonitrile Butadiene Styrene– (ABS)

Properties

Hard, rigid amorphous thermoplastic with good impact strength and weather resistance. It contains a rubber content which gives it an improved impact resistance. Available with different textures and finishes in a range of thickness. Available in Fire Retardant and UV stabilised grades.

1.2.2 Polystyrene(H.I.P.S)

Properties

One of the most widely used materials An easy forming amorphous thermoplastic. Thermoforms with ease utilising low temperatures and fast cycle times. Available with different textures and patterns. No pre drying required. Poor UV resistance –not suitable for outdoor applications.

1.2.3 Polypropylene – (PP)

Properties

PP is a semi-crystalline thermoplastic which has difficult form characteristics with sheet sag inevitable. Chemically inert and very flexible with minimum moisture absorption make it suitable for a wide range of applications. High forming temperature but no drying required. Many grades of PP are available containing fillers and additives. Co polymer as opposed to homo-polymer PP is recommended for vacuum forming, as the co polymerisation process helps reduce stiffness and broaden the melt and glass transition temperatures increasing thermoforming ability.

1.2.4 Polyethylene – (PE)

Properties

PE is a semi-crystalline thermoplastic with similar forming properties to PP. Good heat control with sheet level required for successful forming. High shrinkage rates but good chemical resistance and strength. Available also as a cross linked closed cell foam (PLASTAZOTE) - ideal for packaging and liners. Formability.PE – Difficult. PE FOAM – Good but form at lower temperatures to prevent surface scorching.

2. METHODOLOGY

2.1 Heating

The first step consists of heating a sheet of plastic to make it malleable. This phase helps to achieve a high quality forming and optimizes forming cycle performance. Since plastics do not conduct heat well, it is vital to adjust the heating time based on the thickness of the sheet, the efficiency of the heating system, as well as the colour and nature of the material. The heat must be distributed evenly for an ideal result.

2.2 Forming

Once the sheet has softened, it can be easily formed into the shape of the selected mould. Male (convex) and female (concave) moulds can be matched to obtain parts. The malleable plastic takes the shape of the mould and results in the desired shape.

2.3 Cooling

Forming is followed by cooling and is an important step to obtain a uniform product. It's important to allow the part to properly cool so that it can be removed from the mould without warping, flaws or sticking. The hardening period depends on the thickness of the part and the efficiency of the cooling system. A transition period is required between cooling and cutting since the part shrinks at room temperature[4]. This is the removal process. Rest assured, they are very attentive to detail and make sure that parts are always completely cooled in order to guarantee the best results and impeccable products.

2.4 Cutting/Trimming

The last phase consists of finishing the parts, which is done by cutting or trimming your products. The facilities are equipped with high performance tools. Thanks to our Fanuc robot, we can drill and cut your parts quickly and precisely. This also increases the consistency of parts.

3. COMPONENTS

3.1 RADIANT HEATERS

Quartz emitters provide medium wavelength radiation and can be the most preferred source of heat when rapid heater response is needed. The heaters are comprised of a series of quartz tubes running parallel to each other within a highly reflective aluminized steel housing. Each tube contains a coiled resistance wire available in a variety of wattages and voltages. Watt densities up to 30 w/sq. inch (4.65 w/sq. cm) are available. The large variety of sizes, shapes, and watt densities allows quartz emitters to be highly useful in zoning arrangements such as plastic thermoforming sheet-fed applications where complex heating patterns are needed, high-speed roll-fed processes, and machines requiring precise zone control because they are small in size, and can easily be put in larger panels. Some of these emitters are approximately the same size as our Salamander ceramic infrared heaters (FFQ style=FTE size ceramic heater, HFQ style=HTE size ceramic heater, HSQ style=HSE size ceramic heater)

Fig 5.1 Radiant Heater

3.2 VACUUM PUMP

When dealing with vacuum forming machines using the industry standard "pump and Tank" systems, make the tank large enough so that there isn't too much vacuum loss at the end of the forming cycle (large parts are worse). Then make the pump large enough to recharge the tank quickly to a usable level before the next part is ready to form. When evacuating a tank, the pressure will drop very quickly at first, then get real slow at the very end. If your pump is too small, it will never seem to get that last few inches of vacuum that the pump is capable of.

1. Use one gallon of tank capacity for every 25 to 45 square inches of platen area.

2. Use 1 CFM of pump flow for every 2-4 gallon of tank size.

Fig 5.2 Vacuum pump

5.3 WOODEN BOX

Calculate the dimensions of a shallow box with a footprint slightly larger than your frame; mine was the height should be enough to let you mount the vacuum nozzle attachment along one side.When you have the dimensions, cut 4 side pieces and a bottom out of plywood or other material, accounting for material thickness again. Cut a top panel for the box out of pegboard, large enough to overlap all 4 sides. The pegboard’s holes are used to suck air from under and around the form.

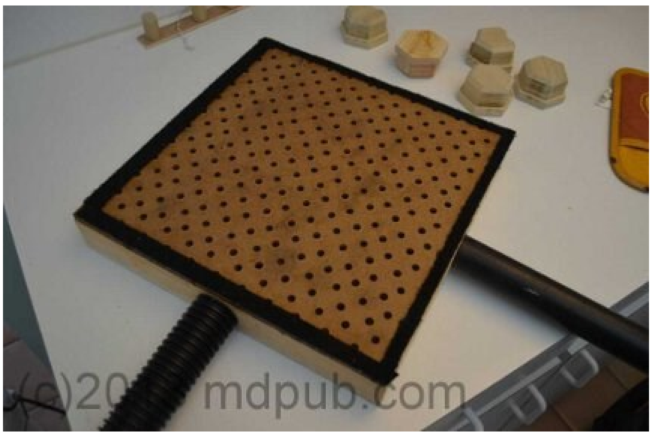

Fig 3.3 Wooden box

3.4 WOODEN FRAME

Measure the interior of your oven, then subtract a few inches from the width and depth for clearance. This gives the size of the biggest frame you can make, which in turn determines the maximum size sheet of plastic you'll be able to mold. Measure and cut the lengths of you need to make your frame, allowing for the thickness of the sides. Make square cuts with your favorite saw: circular, jig, or handsaw.

Fig 3.4 Wooden Frame

Assemble the frame using 2 screws in each corner, for maximum strength. Drill pilot and clearance holes before fastening, and stagger the screws so as not to split the wood. The only critical feature of the frame is that it must lay flat with no gaps or high spots. This will ensure a good air seal when you vacuum form.

3.4 STAND FOR VACUUM MACHINE

Fig 3.5 Stand for Vacuum machine

In contrast, lower grades of rebar are twisted when cold, work hardening them to increase their strength. However, after thermo mechanical treatment (TMT), bars do not need more work hardening. As there is no twisting during TMT, no torsional stress occurs, and so torsional stress cannot form surface defects in TMT bars. Therefore TMT bars resist corrosion better than cold, twisted and deformed (CTD) bars.

3.5 MOULDS

Here three wooden mold pins are sitting on the pegboard. These pins are the shapes I need to reproduce many, many times. They are a funny shape, and difficult to machine by hand. I machined these three with a CNC router my brother and I built.The idea is that I will make molds of them using vacuum forming, then fill the molds with plaster to make all the copies I need. The pins have been sprayed with a teflon mold release agent. This is only necessary because no relief angles were designed into these pins, and the plastic holds really tightly onto them after vacuum forming.

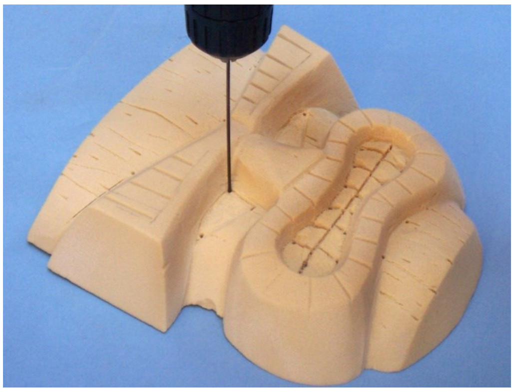

Fig 3.6 Mould Material

4. FABRICATION & ASSEMBLY

The fabrication work is consists of arrangement of the whole setup in a suitable manner. If we looking for our vacuum forming Machine, we arranged the machine in the vertical manner. This is the main Creativity of the Vacuum forming machine. Usually, the Vacuum forming is done under separate Places. Heating Process will be done on one place and the other vacuum forming will takes place on the other area, So, we Planned to Fabricate the Whole Setup in the Vertical manner.

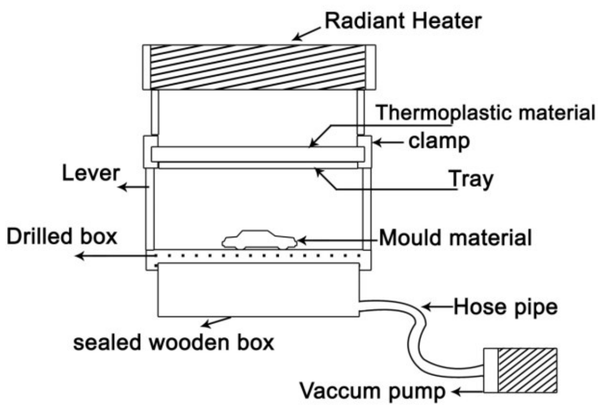

Fig 4.1 CAD Diagram of Vacuum Forming Machine

4.2 ASSEMBLY

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4.2.1 Heater Assembly

The Heater is kept at the top of the stand, The design of the stand is carefully formed otherwise the heater will be damaged due to the friction Between the Heater and the whole setup is mounted in a vertical manner. We are using the Radiant heater on the setup, so the dimensions of the stand should be neatly. We are using the Quartz tube Heater and this is placed Top of the stand.

4.2.2 Frame Assembly

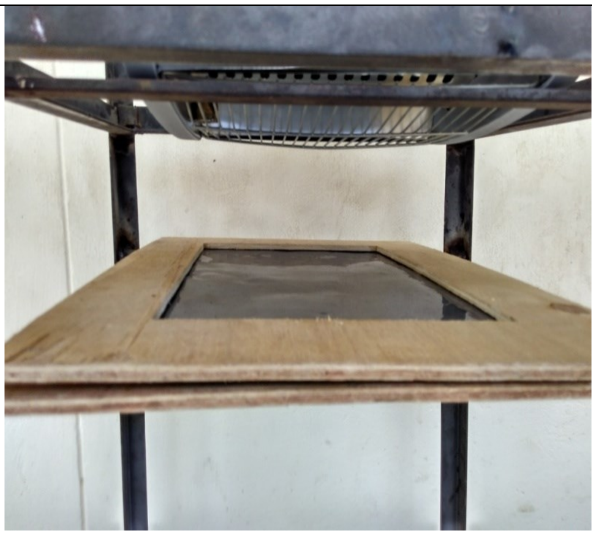
The Frame plays an important role in the vacuum Forming process, because the Plastic material is mounted on the Frame and this will be fixed on the stand slightly below the Radiant Heater. This is done by the stand supports like a Burner link. The Frame should be in the correct manner in the setup assembly. Usually the Frame of the Vacuum Forming Machine is made up of Plywood materials.

4.2.3 Sealed Box

The sealed box plays a vital role in the Vacuum Forming machine. This is usually made up of Plywood material and they are cut into several portions, The assemble like a Box with Tightly sealed containers and the one end of the box is drilled by the circular driller and this side will be connected with the circular pipe and the upper surface of the wooden box is Drilled with the 3mm drill bit, so that the vacuum forming process is working efficiently.

4.2.4 Vacuum Pump

The pump helps to the materials for forming efficiently the final product, the vacuum pump consists of 1100 w and this provides the suitable vacuum inside the contained sealed box. The vacuum pump is kept at the bottom of the stand. The hose pipe is connected with the wooden box.



5. DESIGN CALCULATIONS:

5.1 Radiant Heater Ratings

Brand Name : USHA

Model number : 3002-QH

Type : QUARTZ TUBE

Heat Mode : HIGH, NORMAL, LOW

Power Consumption : 1200W

Switch Type : TIP OVER SWITCH

5.1.1 Dimensions of Radiant Heater

Weight : 6 Kgs

Width : 30 Cms

Depth : 15 Cms

5.2 Vacuum Pump Ratings

Brand Name : Modi-Hoover

Model Number : S-3858

Frequency : 50hz

Power Consumption : 1100W

Voltage : 220-240 V

Suction Power : 150 W

Dust chamber : 2 litres

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Hose pipe Diameter : 3 Cms

DIMENSIONS OF VACUUM MACHINE

Size of the Wooden Sealed Box: 40cms*40cms*10cms

Size of the Drilled Plate: 40cms*40cms*2cms(3mm drill)

Size of the Stand: 40cms*75cms*(4 Pillar)

Top Position of the Machine: 32cms*40cms*2cms

Radiant heater is placed Dimensions: 30cms*15cms

Size of the Tray: 32cms*42cms*1cms

Height of the Entire Equipment Setup: 0.75 mts

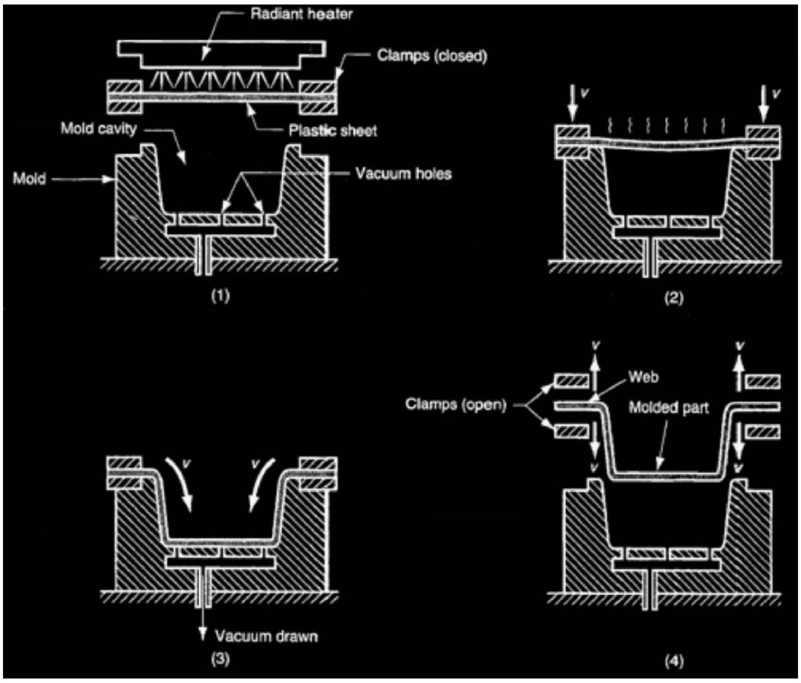

Fig.5.1 Conceptual diagram

Stand of Distance = 10 centimeters

To calculate the rate of Heat transfer Rate

1) q = hc A (Ts-Ta)

Where,

q=Heat transferred per unit time (W).

A=heat transfer area of surface (m2) =40 m^2.

h c=convective heat transfer coefficient of the process
50 W/m^2K (assumed)

Ts=Temperature of surface =1000°c

Ta=Temperature of air =350 ˚C

- q=50*40*(373-308)
- q=50*40*(65)
- q=50*2600
- q=130000 W

Heat transferred per unit time =130000 W=130 KW

2) Standard values for Plastics

MATERIALS	GLASS TRANSITION TEMPERATURE	TIME OF HEATING (Thickness of Sheet=3mm)
High Impact PolyStyrene(H.I.P.S)	94^0C	90 sec
Acrylonitrile Butadiene Styrene (ABS)	88-120^0C	120 sec
Polypropylene(PP)	85-100^0C	150 sec
Acrylic/PVC	105^0C	90 sec
Polycarbonate(PC)	150^0C	180 sec

Tab.5.1. Standard values for Thermoplastic Materials

6. RESULT AND CONCLUSION

Thermoforming is often utilized for production quantities of 100 to 8000 annually, offering lower tooling costs, rapid product development cycles, and parts with color and texture. However, there are times where other plastic manufacturing processes such as plastic injection molding are a better choice. These types of circumstances may include the need for high volumes and very complex, detailed product designs. Vacuum forming is a plastic thermoforming process that involves forming thermoplastic sheets into three-dimensional shapes through the application of heat and pressure. The above fabricated machine is used to form turnpikes, small plastic cases and for industrial shadow boxes for tools.

ADVANTAGES OF VACUUM FORMING MACHINE

- ✓ This manufacturing process makes use of plastic sheets that are higher in quality and have good durability as compared to the ones used in other methods.
- ✓ This process is known to have a good speed when compared to other manufacturing methods, that is once the designs are confirmed, the thermoformed parts can be ready within a month which is not possible in other methods. This speed in production, in turn enables delivery on time.

- ✓ This process enables the manufacture of a wide range of custom-made products since it is believed to be the only method by which plastic sheets can be molded into bigger objects. This process also has a wider design scope.
- ✓ The plastic products manufactured by this process are able to meet the requirements of companies that demand highly specific dimensions for the same. Moreover, they are quite adaptive to the design needs of customers.
- ✓ Almost all types of plastic can be used in this process, which is not the case with the other methods.
- ✓ The costs involved in tooling and engineering are quite low, which is another great advantage over other methods as it makes this process ideal for prototype development and low-volume production

DISADVANTAGES OF VACUUM FORMING MACHINE

- ✓ During this process, the plastic sheets that are in a pliable state can break due to excessive stretching under certain temperatures. This in turn leads to wastage and about 20% more use of plastic that results in higher process costs.
- ✓ Due to the use of higher-quality plastic sheets, this method is costly (about 50 % more) as compared to other methods.
- ✓ In this process, only one side of part is defined by the mold.
- ✓ Here, the parts that include sharp bends and corners are not easy to produce and internal stresses are common.

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