Vacuum forming equipment in dentistry: A narrative review.

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Abstract

Objective: To concise existing peer reviewed literature provide valuable information and a narrative on vacuum forming equipment and the materials used in Prosthodontics.

Background: In dentistry, vacuum formers are utilized to create imprints of opposing bites and fabrication of various dental appliances, including splints, bleaching trays and orthodontic appliances. Though vacuum formers are used extensively, there is lack of a concise knowledge-base on this subject.

Methodology: English based literature online and offline, published from 1986 to 2023 is considered to obtain information. This has been analysed and scripted in a contextual manner.

Results: Knowledge and information on vacuum forming equipment and materials used in Prosthodontics will contribute in better understanding and handling of the equipment leading to improved clinical application and research.

Conclusion: It represents the most basic thermoforming technique and relies on the utilization of vacuum suction pumps to carry out the process. It is particularly advantageous for small-scale production due to its flexibility, time efficiency, cost effectiveness, and consistency.

Application: Vacuum formers are utilized to create imprints of opposing bites and for various dental appliances, including sports mouth guards, occlusal splints, bleaching trays, and orthodontic appliances.

Keywords: Acrylonitrile Butadiene Styrene, pressure forming, vacuum forming equipment.

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Introduction

The utilization of vacuum formed plastic initially emerged as a means to enhance the visual aesthetics and promotional aspects of products. This technology originated from the developments in molding and vacuum casting techniques during the 1940s and 1950s. The inaugural equipment, patented in 1950, was employed for fabricating screen covers (Figure 1). Subsequently, through the implementation of diverse methods and solutions, a definitive machine for vacuum forming plastic sheets was patented in 1964.

Numerous vacuum forming machines trace their origins back to an earlier concept that dictated the removal of surplus air during any molding or casting process by means of vacuum application. The extraction of entrapped air from the tools to be casted plays a pivotal part in various forms of molding and technologies for casting. This step is crucial as the presence of trapped air can result in structural weaknesses within the manufactured piece, rendering it incapable of meeting design requirements and susceptible to cracking or breaking. To overcome this issue, vacuum is applicative to eliminate any entrapped or abundant air, therefore ensuring a flawless and uniform distribution of the mold material.[1]

Enhancements to the technology were achieved by introducing a method in which the plastic plate is affixed to a mount and subsequently subjected to rising temperature prior to the molding process. Through this heating process, the plastic sheet undergoes softening, attains a malleable state, and becomes more amenable to shaping. The patent for the heat-facilitated vacuum forming machine was granted on August 27, 1968.[2]

Vacuum forming apparatus stands as one of the earliest and countless widely employed technique for processing thermoplastics. In contemporary times, vacuum formed plastic products can be observed in almost every sphere. These products encompass a wide range, including simple packaging, toy cars along with their packaging, prototypes, and more.[3]

Vacuum forming is a manufacturing process that involves the shaping of a thermoplastic sheet of specific thickness. Initially, the sheet is heated to an optimal temperature that allows for proper forming. Subsequently, it is stretched to attain a predetermined size and geometry while a vacuum is applied. The vacuum facilitates the precise alignment of the sheet with the forming tool. Once aligned, the sheet is cooled, thereby solidifying and maintaining its formed shape permanently.

After sufficient cooling and hardening, the work piece is carefully extracted, ensuring the preservation of its surface integrity and shape. Subsequently, post-processing procedures are carried out, primarily involving the removal of any excess material.[4,5]

The commonly utilized thermoplastics for vacuum forming encompass high impact polystyrene, polyvinyl chloride, acrylonitrile butadiene styrene, polypropylene, and polycarbonate.[5]

Principle of vacuum forming (Figure 2)

The dissimilarity among Thermoforming, Vacuum Forming, and Pressure Forming lies in the methods used to shape a plastic sheet after heating. Thermoforming refers to the overall process of heating the plastic sheet to render it flexible, followed by shaping it in predetermined molds and subsequently trimming the final product. Within the broader category of thermoforming, two specific types can be distinguished:

- Vacuum forming
- Pressure forming

Vacuum Forming:

During this process, the application of vacuum pressure is employed to shape the thermoplastic plate which is heated into the appropriate configuration. The thermoplastic plate is positioned on the mold’s surface and secured using a clamping unit. The plate will be heated till it reaches a softened state, following which vacuum pressure is swiftly applied. A surge tank is utilized to expeditiously remove air from the middle of the mold cavity and the plate. Once the vacuum is established, the plate accommodates to the shape of the mold cavity. Subsequently, the formed component is cooled and released from the mold cavity.

Pressure Forming:

The pressure forming technique is closely allied to vacuum forming, with the key distinction being the higher level of air pressure utilized. In this procedure, a preheated plastic plate is positioned on the top of the mold, followed by the rapid application of pneumatic pressure onto the sheet.

Vacuum Forming vs Pressure Forming:

The primary distinction between Vacuum Forming and Pressure Forming lies in the number of molds utilized during the manufacturing of their respective products.
Vacuum forming involves the use of a single mold and a vacuum pump. The heated plate is placed onto the mold, and a vacuum is used to securely position it within the desired shape of the mold. This method is commonly employed in the production of contoured packaging for food, electronics, and similar items (Figure 3).

On the other hand, pressure forming utilizes two molds. The sheet is positioned within one mold and then pressed by applying the second mold onto it, instead of relying on suction from a vacuum pump. This process facilitates the creation of precise and visually appealing molds, such as casings for appliances. Additionally, pressure forming is highly suitable for manufacturing plastic parts that require uniform shaping and a greater depth within the mold.[6]

Materials used in vacuum forming:

Vacuum forming can be applied to a range of thermoplastics, although specific materials commonly utilized in vacuum forming include:

Polycarbonate (PC)

Polycarbonate (PC) is a plastic polymer widely employed in the production of various machine components. It is favoured for its exceptional durability, being virtually unbreakable, highly resistant to damage, and often UV protected on one or both sides. Furthermore, polycarbonate boasts a significantly lighter weight compared to glass, making it easy to install and handle within machinery. This material finds application in diverse products such as light diffusers, skylights, and aircraft trims.

Polystyrene (PS)

Polystyrene (PS) stands out as an exceptionally versatile thermoplastic material available in various formulations. In its unmodified state, polystyrene exhibits moderate strength, precision, brittleness, and rigidity. It also possesses desirable electrical properties, dimensional stability, cost-effectiveness, versatility, and ease of processing. These qualities make it widely utilized in the realm of food packaging, as well as for disposable cups and plates.

Polypropylene (PP)

Polypropylene (PP) is another plastic polymer extensively employed in the vacuum forming process for specific applications such as model making, crafts, and report covers in educational and office settings. The sheets composed of polypropylene are characterized by their inflexibility, semi-rigidity, and notable resistance to high temperatures, fatigue, and chemicals. Moreover, they exhibit crystalline structure, lack polarity, and display a translucent appearance.

Polyvinyl Chloride (PVC)

Polyvinyl Chloride (PVC) is a readily available thermoplastic that is utilized in significant quantities. It offers exceptional cost-effectiveness alongside excellent tensile strength, rigidity, and higher density compared to other plastic polymers. PVC is also environmentally friendly and boasts remarkable chemical resistance. Its primary applications lie in commercial settings, encompassing activities such as digital and screen printing, laminations, and vinyl lettering.

Polyethylene (PE)

Polyethylene (PE) is a plastic sheet derived from petroleum, characterized by its exceptional resistance to water and chemicals. It maintains high stability even in cryogenic environments, possesses a low coefficient of resistance, and exhibits high malleability. Due to its affordability and suitability for a wide range of environments, polyethylene is extensively utilized.

Polyester Copolymer PETG

Polyester Copolymer (PETG) is a thermosetting plastic renowned for its remarkable durability, strength, and resistance to harsh environments. It is favored in vacuum forming due to its ease of molding, dye cutting, and shaping capabilities.

Acrylic PMMA

Acrylic PMMA is a widely employed plastic sheet known for its durability, transparency, ease of molding, and cost-effectiveness compared to more fragile and costly glass. It finds application in various industries, including automotive (windows), electronics (smartphone screens), and even in aquariums.

Acrylonitrile Butadiene Styrene

Acrylonitrile Butadiene Styrene (ABS) is a water-insoluble thermoplastic possessing excellent chemical resistance, impact resistance, abrasion resistance, and stress resistance properties. It is a rigid, hard, and stable plastic material with favorable electrical properties. ABS is commonly used in the manufacturing of rigid pipes, automobile components, and car wheels, among other applications.[7]

Parts of equipment (Figure 4 and 5):

1. Foil tension ring
2. Foil reception for foils Ø 120 mm and Ø 125 mm
3. Heating cap (infrared lamp)
4. Display 5 Button "Setting"
5. Pressure regulator
6. Pressure chamber
7. Reception for granules and plate reception
8. Closing device for pressure chamber

How It Works:

Model Preparation before vacuum forming:

Base: The model's base should be kept thin to avoid thinning of the material and loss of details. Excessive base thickness can negatively impact the final product.

Stone: It is recommended to use high-quality stone or gypsum that can produce a tough and dense model. Brittle materials may generate dust, which can settle into the finished appliance and affect its quality.

Undercuts: Ensure that the trimmed sides of the appliance are flat and cut precisely at a 90˚ angle. It is important to avoid creating undercuts or angles that extend into the base, as they can result in a vacuum lock and hinder the creation of intricate details. If possible, consider flaring out the base slightly during the trimming stage, as this can offer certain advantages.

(Avoid using wet casts or excessive silicone spray, as the moisture can be drawn into the vacuum system and cause damage to the motor.)

Vacuum forming process:

Adjust the positioning of the heating unit towards the back and shift it to the left. Once the repositioning is complete, switch on the heater. Upon activation, the indicator light will illuminate, serving as a visual confirmation of the heater being turned on.

It is necessary to allow the heater for preheating. This step is particularly crucial when working with materials that are .040 or thinner. Such materials have a tendency to heat up rapidly, thus it's advisable to ensure that the temperature of heater is stabilized prior to its use.

Pull the latch knob to access the above plate, to open. Position the forming material sheet onto the below plate. Lower the above material plate onto the placed material, and fasten it by engaging the latch.

Hold the handles situated at the rear of the bottom plate and lift both plates. To maintain the raised position of the plates, rotate the left handle to securely lock the pin, this will effectively secure the plates in place.

Position the cast (made of stone, gypsum, or similar material) onto the vacuum plate.

Position the heating unit directly over the sheet. Once the sheet starts to sag, carefully lower the sheet onto the cast placed on the vacuum platform. (It is important to monitor the material closely during heating as it heats rapidly. Allowing the material to sag excessively renders it unusable. In severe cases, the sheet may get drawn into the vacuum motor, resulting in blight of the motor.)

Thinner materials with a thickness of .040 or below exhibit diminished sagging tendencies compared to thicker materials measuring .150 or greater.

To finalize the adaptation, transition the switch from the left heating orientation to the right vacuum orientation. When working with thicker materials, it is advisable to extend the duration of the vacuum operation for achieving finer detail.

Deactivate the vacuum motor. Then, let the processed sheet cool before proceeding to open the frame. Release the frame knob and unlatch the frame to extract the adaptation.

Utilize the frame latch knob to securely hold the frame in an open position, which enables the gaskets to release heat.

To detach the cast from the adaptation, begin by using scissors to cut off the excess material. Trimming should be done close to the cast to make it easy to handle.

To detach the adaptation from the cast, utilize a suitable tool such as a knife, disc, or grinding wheel that is specifically designed for trimming excess acrylic.

Conduct meticulous trimming using scissors, a razor, or an electric knife to achieve professionally finished results.

Conclusion

Vacuum forming is a traditional method employed in the production of plastic goods. It represents the most basic thermoforming technique and relies on the utilization of vacuum suction pumps to carry out the process. This approach involves two distinct types of molds, namely the male mold and the female mold. To manufacture plastic materials via the vacuum forming process, a series of steps are followed, including clamping, heating, sheet levelling, pre-stretching, plug assist, vacuuming, cooling, trimming, and finishing. Various types of plastic materials are suitable for this procedure, such as polycarbonate, polyethylene, acrylic PMMA, PVC, and others. It is particularly advantageous for small-scale production due to its flexibility, time efficiency, cost-effectiveness, and consistency. However, the vacuum forming process has limitations, such as concerns regarding the ethical use of plastic and its suitability for only smaller-scale production and thin-walled materials.

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FIGURES

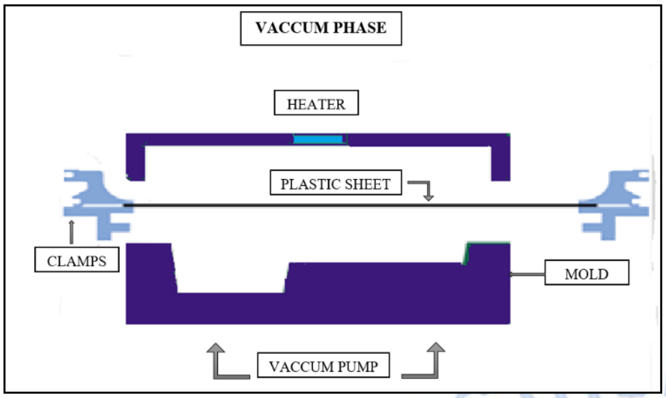

Figure 1

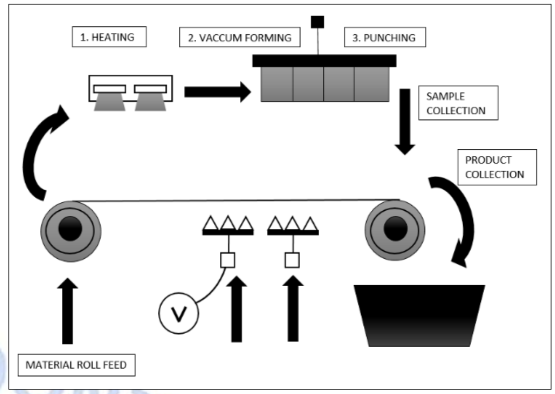

Figure 2

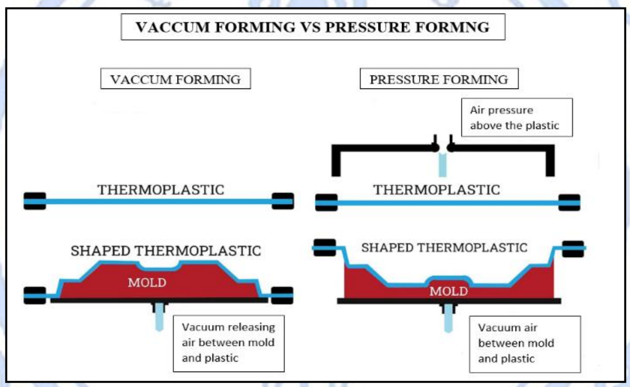

Figure 3

Figure 4

Figure 5