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RAPID FABRICATION OF FUNCTIONAL MOUTHGUARD USING RAPID TOOLING APPROACH

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ABSTRACT

This paper presents the fabrication process of custom-made mouthguard with added features of air flow channel by using rapid tooling approach. Impression process was conducted in order to produce dental stone that will be used in thermoforming process to fabricate the custom-made mouthguard. Computer-aided design (CAD) were utilized to prepare the air flow channel's design before attaching it at the custom-made mouthguard and then forming the master pattern for the vacuum casting process. The design was printed using 3D printer machine. Two samples of mouthguard with different number of layers and thicknesses of ethylene vinyl acetate (EVA) sheets were produced by using thermoforming. The resulting mouthguards was analysed and it was concluded that the thicker ethylene vinyl acetate (EVA) sheets will require higher melting and and also cooling temperature. Same goes to the hardness of ethylene vinyl acetate (EVA) will affect the melting and cooling temperature. Silicone mould was produced by using vacuum casting process. The mixture of silicone was de-gassed in vacuum to remove the presence of air bubbles that will affect the mould and product. Cold cure acrylic resin of Meliodent rapid repair was used as the material of the features part. The resulting custom-made mouthguard with added features was analysed. The acrylic resin attached with the ethylene vinyl acetate (EVA) sheets with the aid of monomer that applied onto the surface of ethylene vinyl acetate (EVA) before pouring the resin. Although the process is successfully adhered both of the materials, the strength of the bonding is still merely weak and might detached if some force applied on it. Therefore this mouthguard with added feature is not ready to be used in sports due to its weak bonding strength. Further improvements should be done to enhance the fabrication process of the custom-made mouthguard with added feature.

Keywords: custom-made mouthguard, vacuum casting, thermoforming.

INTRODUCTION

With the emergence of Rapid Prototyping (RP) system, the concept of Rapid Tooling (RT) has arrived. The challenge and greatest potential of Rapid Prototyping lies in providing a direct integrated route to tooling through reduced lead-time and production cost. Even though Rapid Prototyping parts may be produced directly in layers, most Rapid Tooling is produced indirectly which mean by using Rapid Prototyping parts as the pattern like Silicone Rubber Mould and Metal Spray Tooling [1]. Vacuum casting is a rapid tooling technique widely being used in industry to obtain plastic functional parts. It is one of the simplest and oldest rapid tooling techniques, where a rapid prototyping positive pattern is suspended in a vat of liquid silicone. Vacuum casting have been extensively applied because of the great performance in creating good conditions for decisively reducing gas porosity, since air is evacuated from the die cavity [2].

The custom-made mouthguards was widely used by athletes due to its superior level of protection and eliminate mouth injuries compared to stock mouthguard and also boil and bite mouthguard. It was vacuum-formed on a stone model of a maxillary dental arch and fits better than the "store-bought" mouthguard. The mouthguards fulfil all the criteria for adaptation, retention, comfort, and stability of material. The most commonly used material to fabricate the mouthguard is the ethylene vinyl acetate (EVA). Custom-made mouthguard with added features of integrated breathing channels allow for free air flow and enhance the breathing mechanism of an athlete.

Type of mouthguard

Mouthguards are widely used in various types of fields such in medical and sports. In medical field, mouthguard are used to solve some medical problems like snoring and sleep apnea and also treating Bruxism or Tooth Bleaching [3] [4]. In sports, mouthguard are widely used for many years since late 1800s. There are three types of mouthguard in sports; Stock Mouthguard, Boil and Bite Mouthguard, and Custom-Made Mouthguard.

Stock mouthguard

Stock mouthguards are the least preferred type. It was commonly found at sports goods and department stores. These mouthguards are the cheapest, very ineffective, and are only available in a limited number of sizes and do not require a custom fittings. For comfort, they are can be modified by the athlete for better fit. This can maximize the mouthguards ability (Figure-1). Stock mouthguards have been proven that it provide only a low level of protection [5]. If the wearer is rendered unconscious, the mouthguard may become unseated and cause an airway obstruction [6].

Figure-1. Stock mouthguard.

Boil and bite mouthguard

Boil and Bite Mouthguard are popular over-the-counter mouthguard that user warms in hot water and fit to his own teeth (Figure 2). These mouthguards does not provide the proper thickness, comfort, or critical protection of the posterior teeth. They are made of a thermoplastic material that fit and formed in the mouth with the use of the lips, tongue, cheeks, and biting pressure after immersing it in boiling water. Often, clenching pressure is required to obtain satisfactory retention due to inaccurate fit. Generally, this mouthguard do not cover the posterior teeth. One study reported that they did not perform any better than the stock mouthguard. The softening temperature is approximately 180 °F (82 °C) due to submerge into the boiled water [7].

Figure-2. Boil and bite mouthguard.

Custom-made mouthguard

Designed by a qualified dentist, these mouthguards provide comfort, correct thickness, and maximum protection of all teeth, including the posterior teeth. The Custom Laminated Mouthguard of 2 or more layers, sometimes addition of reinforced layer, exhibit excellent fit and durability. Compared to all other types of mouthguards, Custom Laminated Mouthguards have the best combinations of power absorption and dispersion and therefore provide superior protection [8]. In order to fabricate the custom-made mouthguard, a dental stone model is needed for thermoforming. The process producing dental stone is impression. Basic principles of thermoforming are the thermoplastic sheet is heated until it softens. Then the hot and pliable material is forced against the contours of a mold by using vacuum pressure and finally the mould is held together to allow the plastic to cool down until the plastic retains its shape. There are two types of thermoforming machines used in the construction of custom guards. The traditional apparatus employs the use of a vacuum table to adapt the heated EVA material to the cast. Ethylene vinyl acetate (EVA) copolymer is the material of choice for fabricating custom-made mouthguards in terms of availability and ease of manipulation. Vacuum casting is a state-of-art for prototype plastic and plaster mould making that able to cast small metal parts and plastic materials. The casting is performed with prepared cast resin constituents or compound, where the resin to be cast will be driven into the mould by atmospheric pressure, while the vacuum will remove the trapped air that will impede the free flow of resin. Casting can be performed manually or automatically [9]. Although vacuum casting has been viewed as theoretically possible for more than 20 years, its commercial viability has recently made possible by the application of microprocessor and refractory technologies. The relative cost to manufacture prototypes using the same prototyping technique with different mould materials depends on several factors, such as geometry and volume part [10].

METHODOLOGY

Impression

A dental stone model is required for the thermoforming process. In impression process, the patient uses their teeth for the impression mould (Figures 3-4) and then the mould will be used to pour the dental stone mixture. Mixture of alginates with the ratio powder to water of 3:3 for upper arch and 2:2 for lower arch was mixed gently and thoroughly. Spread a portion of alginate into the fissures with finger to improve accuracy of the impression before placing the impression tray with the alginate mixture inside the patient's mouth. The mouth is kept fully closed as possible during the few minutes required for the material to set. The alginate was gently removed from the patient's mouth and was cleaned with running water before pouring the mixture of dental stone. Calestone stone powder was used and mixed with the ratio powder to water of 2:1. The mixture then poured into the impression with some vibration applied to make sure the stone mixture filled the deepest part of the impression. The setting time of the stone is about 45 minutes and the base should be trimmed roughly to the correct shape. Figure-5 shows the final customized dental stone model that used for the thermal forming process.

Figure-3. Taking impression.

Figure-4. Impression model.

Figure-5. Dental stone model for mouthguard.

Thermoforming

Two different mouthguards were fabricated. The first one using three layers of EVA (2 mm soft layer + 1 mm hard layer + 2 mm soft layer) and the second one using two layers of EVA (two piece of 2 mm soft layers). An outline was drawn on the model. A liquid separator was applied on the model to ensure the mouthguard can be removed from the model easily. The dental stone model was then placed at the center of the machine. Easy Vac-Vacuum Forming machine with 120V, 50 ~ 60 Hz and 6 to 8 psi (0.42 kg/cm² - 0.56 kg/cm²) (Figure-6). A 2 mm thickness of EVA sheet was secured on a tray below the heating element of the machine and then heated at 320˚C until the foil becomes saggy for about 4 minutes. The EVA tray was pushed downward towards the model and vaccum was switched on for about 3 minutes for cooling down. The formed material on the model was cut facially along the vestibule and 3-5mm below the gingival margin on the lingual (palatal) side by using hot lab knife. The mouthguard was trimmed and an isopropyl alcohol based degreaser was applied on the mouthguard surface before repeating the thermoforming process for the second layer.

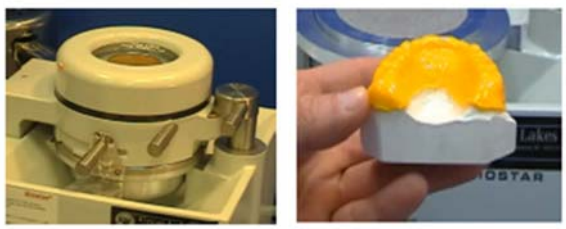

Figure-6. Vacuum forming.

Fabrication of master pattern

The feature to be added at the mouthguard is the air path or air flow located at the frontal upper jaw or in between the canine to canine posture. A master pattern of the feature was constructed for the silicone mould by using the 3D printing technique by utilizing Wanhao Duplicator 4 machine (fused deposition modeling, FDM), (Figure-7). ABS (Acrylonitrile butadiene styrene) filament was used as the material. Also, the master pattern drawing was constructed by using Solidworks design software.

Figure-7. Wanhao FDM machine.

Vacuum casting

Master pattern was prepared with the added features design that has been 3D printed and attached by using re-usable rubber adhesive putty on the frontal area of mouthguard. The master pattern was suspended in a mould box (13 x 10 x 17) cm, as shown in Figure-8. Mixture of silicone rubber with ratio silicone to hardener of 10:1 was prepared and degassed for 5 minutes before pouring into the mould and re-degassed again for 20 minutes. The silicone mold was stored in 40˚C oven for 8 hours to harden. Split the mould into half, remove the master pattern, apply a layer of monomer on the mouthguard surface before re-attached the mould for resin pouring (Figure-9).

Figure-8. Vacuum casting.

Figure-9. Silicon mold.

Figure 2: Suspended master pattern in silicone mould box

RESULT AND DISCUSSIONS

Thermoforming process and completed custom-made mouthguard with added feature was analysed (Figures 10-11). Table-1 shows the comparisons between two different mouthguard with different number of layers of EVA used.

Mouthguard A used three layers of EVA with 2 mm thickness of soft EVA, 1 mm thickness of hard EVA, and 2 mm thickness of soft EVA. Mouthguard B used two layers of EVA with both have the same 2 mm thickness of soft EVA. Thicknesses of mouthguard was measured at the incisal (central incisor between canine to canine), occlusal (second molar), and labial. For mouthguard A, the percentage of shrinkage is around 30% - 40% (frontal part of upper arch) which is 37% and 30%, 15 % on the occlusal part. While for mouthguard B, the average shrinkage is around 22% to 25%.The heating time required is approximately 4 minutes (soft EVA sheet) and 5 minutes (hard EVA sheet). The cooling time is approximately 3 minutes (soft EVA sheet) and 6 minutes (hard EVA sheet). Some defects in thermoforming process are occurred such as delamination (caused by insufficient heat, contaminated surfaces, and slow forming power), trapped air (caused by untrimmed excess stone), and surface contaminations (Figure-12). By using vacuum casting, the acrylic resin attached with the ethylene vinyl acetate (EVA) sheets with the aid of monomer that applied onto the surface of ethylene vinyl acetate (EVA) before pouring the resin, forming the final product.

Table-1. Comparisons of the two mouthguard.

Mouthguard		**A**	**B**
Shore A Hardness		82, 95	82
Melting Temperature (°C)		320	320
Initial Thickness (mm)		2.00 mm + 1.0 mm + 2.0 mm	2.0 mm + 2.0 mm
Final Thickness (mm)	Incisal	3.15	2.97
	Labial	3.35	3.02
	Left Occlusal	4.18	3.10
	Right Occlusal	4.23	3.28
Percentage of Shrinkage (%)	Incisal	37.00	25.75
	Labial	33.00	24.50
	Left Occlusal	16.40	22.50
	Right Occlusal	15.40	18.00
Heating Time (minute)	Layer 1	4	4
	Layer 2	5	4
	Layer 3	4	-
Cooling Time (minute)	Layer 1	3	3
	Layer 2	6	3
	Layer 3	3	-

Figure-10. Custom-made mouthguard.

Figure-11. Defect at air flow hole.

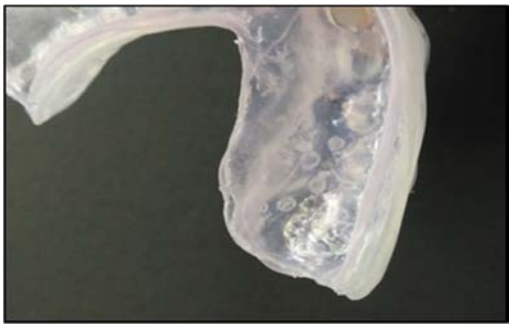

Figure-12. Delamination.

CONCLUSIONS

For the thermoforming process of custom-made mouthguard, it can be concluded that harder EVA sheet require more heating time and also require more cooling time. The general rule is the thicker the EVA sheet (same hardness), the more heating time and cooling time required. Good thermoforming process requires good and high quality of dental stone model. Bubbles, fractures, and any flaws will significantly decrease the quality and affect the thermoforming process. Besides, better equipment and right instruments will give better results of mouthguard fabrication process. Correct temperature, clean working environment to avoid contamination, and the quality of the EVA sheets are also vital in thermoforming process. Acrylic resin and EVA successfully combined by using vacuum casting process. Ethylene vinyl acetate (EVA) and acrylic resin also known as polymethyl methacrylates (PMMA) are two different materials can be attached by using adhesive even though the bonding strength are merely weak due to their mechanical properties of material which are brittleness of acrylic resin and the elasticity of custom-made mouthguard. A layer of monomer applied on the surface of EVA will eventually act as the bonding agent.

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