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Mini Review

Mouthguard Thermoforming of Utilizing Characteristic of Elastomer

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Abstract

Mouthguards can reduce the risk of sports-related injuries such as tooth fracture or avulsion. When forming a mouthguard, the elastomer sheet is molded over a working model using a vacuum or pressure-forming process, both of which are simple to perform but can yield thinner sheets. During mouthguard fabrication, thickness reduction occurs in two stages: heat-softening and pressure-forming. Thickness reduction during heat-softening is largely due to the increase in the sagging distance of the sheet. Thickness reduction during formation is also greatly affected by the shape of the model, and softening state of the sheet. First, we examined ways to uniformly soften the sheet, and found that the measure of the timing by the lowered height of the sheet frame position led to a slow rise in sheet temperature and controlling power on-off of the heater were effective. Next, we investigated the effect of model position in the molding machine on the reduction of mouthguard thickness in the second stage. The shape change during molding was caused by the sheet being stretched while applying a vacuum or pressure. It was suggested that the model position affected the mouthguard thickness, and that the thickness reduction increased when the distance to the model from the frame decreased. This study demonstrates that the proposed method for mouthguard molding is effective and easily regardless of operator skill. These lead to suppression of the thickness reduction and prediction the change in the thickness; it is a matter to be considered when fabricating a mouthguard by thermoforming.

Keywords: Thermoforming; Mouthguard; Softening state; Thickness

Abbreviations

EVA: Ethylene Vinyl Acetate resin; PO: Poly Olefin based elastomer; PS: Poly Styrene based elastomer

Introduction

Mouthguards can reduce the risk of sports-related injuries such as tooth fracture or avulsion [1-5]. When forming a mouthguard, the elastomer sheet is molded over a working model using a vacuum or pressure-forming process (Figure 1, Figure 2), both of which are simple to perform but can yield thinner sheets. Final mouthguard thickness is influenced by factors such as the type of molding machine used, the shape of the working model, the thickness and material of the sheets, and the fabrication method [6-11]. It is necessary to know how each forming method affects the thickness and how the thickness will change after forming. This is because the mouthguard thicknesses and materials influence their effect and safety [1-3,12-16].

Thickness reduction occurs at two stages during mouthguard fabrication. Thickness reduction during heat-softening is largely due to the increase in the sagging distance of the sheet. Thickness reduction during formation is also greatly affected by the shape of the model, and softening state of the sheet [7,10]. In the present study, we examined the softening state and thickness change in order to clarify the shape change of the mouthguard sheet during thermoforming.

Control the softening state of mouthguard sheet

The influence of the sheet softening state on the thickness of the mouthguard will be described. The timing of forming is conventionally judged in accordance with the distance that the sheet sags and the sheet's softening temperature [7]. To avoid poor fit of mouthguards, the sheet temperature of the surface to be pressed against the model must have reached the softening temperature [17-19]. Given the structure of the forming machine, where the non-heated surface is pressed against the model, it was difficult to uniformly soften the sheet using the usual method, because applying enough heat to sufficiently soften the non-heated surface results in excessive heating

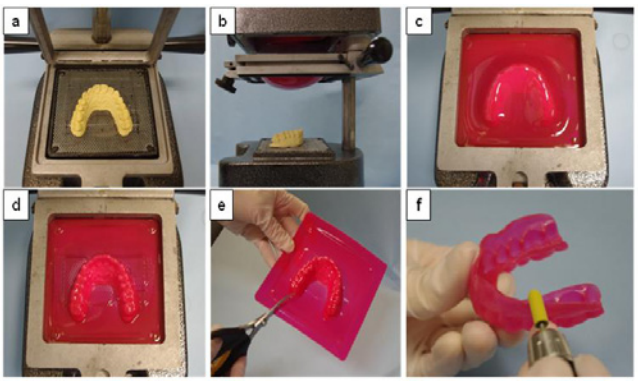

Figure 1: Fabrication of single layer mouthguard by vacuum forming machine. a). placing a model on forming unit, b). Softening of a mouthguard sheet, c). Lower the sheet frame after sheet softened, d). Vacuum formation, e). Trimming of the excess part, f). Morphology adjustment and polishing.

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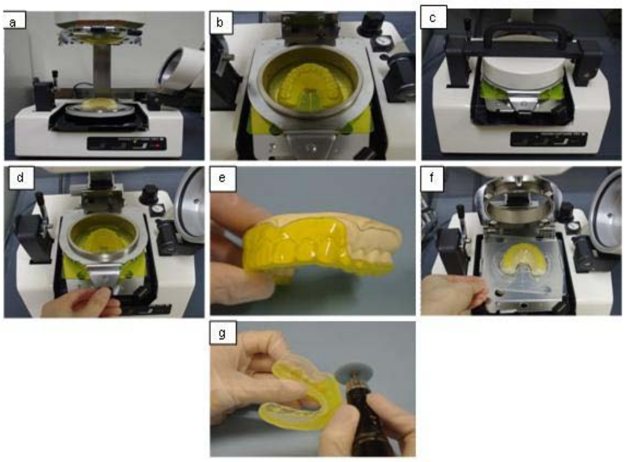

Figure 2: Fabrication of laminated mouthguard by pressure forming machine. a). Placing a model on a forming unit, and softening of a mouthguard sheet, b). Lower the sheet frame after sheet softened, c). Pressure formation of the first layer sheet, d). Remove the mouthguard sheet and the model, e). Trimming of the excess part of the first layer, f). Pressure formation of the second layer sheet, g). Morphology adjustment and polishing.

Table 1: Material and characteristic of mouthguard sheet.

Mouthguard sheet material	Formable temperature	Characteristic
Ethylene Vinyl Acetate resin (EVA)	80–120°C	Low price Many color variations
Polyolefin based elastomer (PO)	85–230°C	No water absorption Heat weldability Good processability
Polystyrene based elastomer(PS)	100–140°C	High elasticity

Table 2: Sheet surface temperature of the center when a 4.0 mm-thick sheet has sagged 15 mm.

	Vacuum forming machine			Pressure forming machine		
Sheet material	EVA	PO	PS	EVA	PO	PS
Heated surface (°C)	137	120	168	143	137	172
Non-heated surface (°C)	100	83	99	112	118	113

of the directly heated surface.

Some of the most commonly used materials can be divided broadly into Ethylene Vinyl Acetate resin (EVA) and Poly Olefin (PO) and Poly Styrene (PS) based thermoplastic elastomers, and the choice of material affect a variety of the mouthguard's characteristics [7] (Table 1). Additionally, previous studies have investigated appropriate sheet material specific heating conditions. For example, the appropriate softening temperature for EVA sheets has been identified as 80-120°C, with deterioration of surface properties occurring at temperatures over this level [20-22]. For this reason, when using EVA sheets the timing of molding is quite strict. Conversely, PO sheets have a broad temperature window (85-230°C) for molding and high workability and heat resistance, so molding them is relatively easy. Thus, temperature control is very important when using EVA sheets to avoid disrupting their material properties, in contrast, when using a PO sheet, the decrease in thickness due to the softening of the sheet should instead be noted.

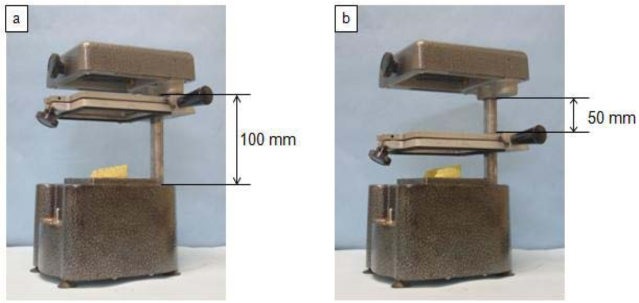

Figure 3: Method of heating with the sheet frame lowered. a). The normally used position, b). The sheet frame was lowered to and heated at 50 mm below the top of the post and molded when it sagged by 15 mm.

Table 3: Sheet frame was lowered and heated at 50 mm from ordinary used and the sheet surface temperature of the center was measured when the sagging distance reached 15 mm.

Sheet material	EVA	PO	PS
Heated surface (°C)	107	94	114
Non-heated surface (°C)	91	88	98

Table 4: Heater was turned off when the sheet sagged by 10 mm from the frame and the EVA sheet surface temperature of the center was measured when the sagging distance reached 15 mm.

Position of sheet frame	Top of the post		50 mm below the top of the post	
Distance of the sheet sagged	10 mm	15 mm	10 mm	15 mm
Heated surface (°C)	127	117	101	98
Non-heated surface (°C)	75	90	73	93

The softened state of the sheet is influenced by the structure of the forming machine. Most forming machines use a single-sided heating mechanism, in which a temperature difference occurs between the heated surface and the non-heated surface [9,19,23,24] (Table 2). Unevenness in softening of the sheet leads to a decrease in the thickness at the second stage (i.e. formation). In other words, the parts of the sheet that are sufficiently softened are more stretched than those where softening is insufficient, so the thickness decreases significantly at these parts. The sheet is stretched more dramatically and consequently tends to become thinner at the parts of the model with sharper peaks; conversely, the changes in thickness are less dramatic in the flat, broad areas [19,23,24]. When extending the heating time or increasing the sagging distance of the sheet in an attempt to avoid insufficient changes in thickness, the reduction in thickness at the first stage (i.e. heat-softening) becomes very high, and there is concern that deterioration of the sheet could be caused by overheating [22,23]. Therefore, if the mouthguard sheet could be uniformly softened as much as possible and at a suitable softening temperature, there would likely be suitable retention of mouthguard material characteristics.

First, we have examined ways to uniformly soften the sheet when using a vacuum-type or pressure-type molding machine, and found that the following two methods are effective. The first method is that of heating with the sheet frame lowered (Figure 3). It can be applied to many vacuum forming machines. In this method, the distance between the molding machine heater and the sheet is increased,

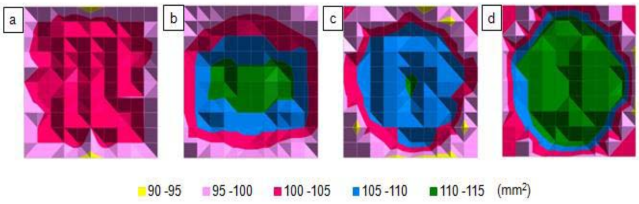

Figure 4: Schematic views of changes in the area of mouthguard sheet. a). vacuum formation (sheet sag of 15 mm), b). vacuum formation (sheet sag of 20 mm), c). Pressure formation (sheet sag of 15 mm), d). Pressure formation (sheet sag of 20 mm).

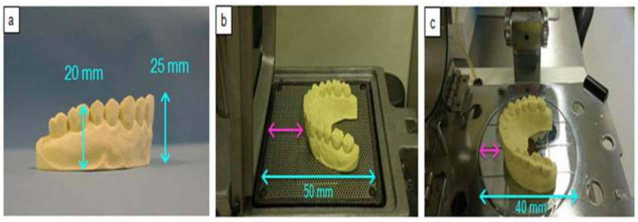

Figure 5: Changes in the thickness reduction rate of the mouthguard were compared when the model position was moved backward and front. a). Working model, b). Vacuum formation, c). Pressure formation.

allowing the sheet to soften slowly and thus avoiding overheating of the directly heated surfaces and insufficient softening of the non-heated surfaces [23,24)] (Table 3). The second method is that the heater was turned off when the sheet sagged by 10 mm from the level of the sheet frame, followed by sheet molding when the sagging reached 15 mm below the sheet frame under ordinary used [23-25]. In this method, while the heated surface cools somewhat after the heater is turned off, the non-heated surface become hotter due to heat from the raised interior temperature, reducing the temperature difference between the heated and non-heated surfaces (Table 4). While some differences can be expected between these methods according to the molding machine structure, in principle each cause a smaller temperature differential between the sides of the sheet than using the conventional method.

Predict thickness of mouthguard after formation

The thickness reduction in sheet that occurs in the first stage was examined [26]. The shape change of the sheet at sagging distances of 15 and 20 mm under normal molding operation (as the 4.0 mm-thick sheet reached the softening temperature) was compared. Cross stripes (10 × 10 mm) were created on the sheets and the anteroposterior and bilateral lengths were used for measurements. The area of each lattice was calculated using Bretschneider's formula. The shape change in the first stage tended to increase slightly more in the central region than at the sheet periphery, and noticeable changes did not occur in the center (lowest point of the sheet sag), so the difference was only about 5% in this area (Figure 4).

The shape change during molding in the second stage was caused by the sheet being stretched while applying pressure or a vacuum [7,10,26,27]. As this point, the sheet was secured on both sides of the frame and was in contact with the model. Next, the sheet was stretched toward the model during molding. So we investigated the effect of model position in the molding machine on the reduction

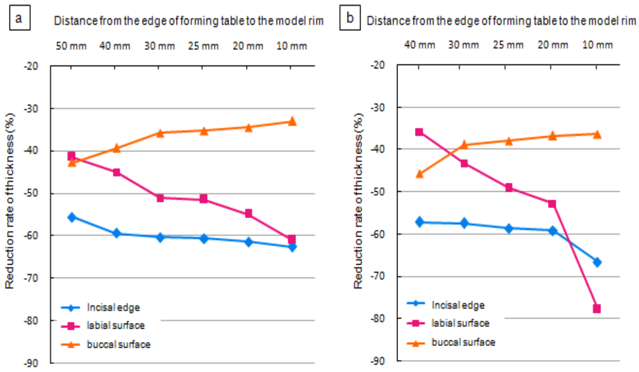

Figure 6: Difference in the mouthguard thickness after formation depending on the installation position of the model. a). Vacuum formation, b). Pressure formation.

of mouthguard thickness. The model position of the control was 25 mm because the height of the model and the distance from the model rim to the sheet frame are same. Then, the changes in the thickness reduction rate of the mouthguard were compared when the model position was moved backward and front (Figure 5). The reduction of thickness of the incisal edge and the labial surface were -60% and -50% at 25 mm for vacuum- or pressure- molding machines. The reduction of thickness of the buccal surface was less (-40% to -35%) because this part of the model was wide and low. At the condition in which the model is placed backward, the thickness reduction for the anterior part (incisal edge and labial surface) was smaller than the control, because the distance to the frame from the model rim was larger than the height of the model (height of the anterior part of the model of 25 mm). The thickness of the posterior part (buccal surface) was larger than at 25 mm, because the distance to the frame from the model was smaller than the height of the model. Conversely, at the condition in which the model is placed front the control, the reduction in the labial thickness was large because the distance to the frame from the model rim was smaller than the height of the model (Figure 6). This was because when the model was covered with a sheet, the sheet was secured on both sides of the frame and was in contact with the incisal edge. Next, the sheet was stretched toward the labial side of the model during molding (vacuum or pressure forming).

Therefore, the model position affected the mouthguard thickness, and that the thickness reduction increased when the distance to the model from the frame decreased. In other words, if the length of the original sheet is insufficient against the amount of deformation of the sheet (that is the sum of the distance from the model rim to the sheet frame and the height of the model), the mouthguard thickness will be affected. The height or the size of the model is different depending on the dentition, and the size of forming unit is different depending on the kind of molding machine used. This implies that the most stable molding is achieved by centering the sheet and the model in the forming unit.

Conclusion

This study demonstrates that the proposed method for mouthguard molding is effective and easily regardless of operator skill. These lead to suppression of the thickness reduction and prediction the change in the thickness, it is a matter to be considered when fabricating a mouthguard by thermoforming.

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