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The Effect of Thermoforming on Tear Strength of Ethylene Vinyl Acetate Mouthguard Material in Various Thicknesses

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Abstract The effect of thermoforming on the tear strength of ethylene vinyl acetate (EVA) mouthguard material (Bioplast®) has not been widely investigated. The present study compared the tear strengths of non-processed and processed EVA specimens in various thicknesses. Two groups of EVA sheet (non-processed and processed) in three different thicknesses of 3, 4 and 5 mm were used in specimen fabrication. The processed EVA sheets were achieved by forming the EVA sheet on the cylindrical stone model with the pressure-molding device (Biostar®). Twelve of tear strength specimens of non-processed and processed group in each thickness were prepared following the modified ASTM D 624-00 guideline. The tear strength test was conducted using universal testing machine (Lloyd® 1K series) with the speed of 500 mm/min. The mean thickness and tear strength of the non-processed and processed specimens in each thickness were compared using independent T-test. The differences in the mean tear strength for each thickness of non-processed and process specimens were determined using one-way ANOVA. The mean tear strength and mean thickness of processed EVA specimens was significantly lower than the non-processed EVA specimens for every thickness ($P \leq 0.05$). There was no significant difference in the mean tear strength of EVA specimens among each thickness in both non-processed and processed groups. It can be concluded that the thermoforming process has the significant effect on the tear strength of the EVA mouthguard material formed by pressure molding device in every thicknesses. The tear strength of processed specimens were significant lower than the non-processed. Thus, it is more relevant for testing properties of the processed mouthguard material that the mouthguard material before processing.

Introduction

Mouthguard is a removable dental prosthesis made of resilient material which is useful in protecting the teeth and surrounding structures from injuries [1]. It has been recommended by the American dental association to use the mouthguard in 29 sports/exercise activities [2]. Mouthguard can be classified in three categories; custom-made, mouth formed, and stock type [3-5]. The custom made mouthguard has been proved for the superior benefit in dental and oral structure protection due to its fit and adaptation to the oral structure. However, it requires complicated fabrication procedure [4, 5]. The custom made mouthguard can be fabricated in two methods: vacuum-forming process and pressure-forming process [5-7]. The pressure-forming process has been reported to produce the superior mouthgurad product because the manufacturer can control the heat and pressure resulting in less thickness reduction [6, 7]. Currently, the widely used materials for mouthguard fabrication are ethylene vinyl acetate (EVA) copolymer [8]. There have been a number of studies about the physical and mechanical properties of mouthguard material including energy absorption, hardness, elasticity, water absorption, and tear strength properties. However, most of those studies focused on the mouthguard material sheet before thermoforming that may be less relevant for clinical application [8].

The changing in the physical and mechanical properties of mouthguard material after thermo-forming has been reported in many studies during the past decades. Most of those studies focused on some physical properties such as shock absorption, force transmission and behavior of the mouthguard material after force impaction [8]. Tear strength is one of the important and frequently reported properties of the mouthguard material. It refers to tearing resistance of a material and can represent the mouthguard's durability. There have been some studies focused in determining the tear strength of mouthgurad material [9-12]. All of those studies used non-processed mouthguard material. There has been no study reported the tear strength of the moughtguard material after thermoforming process.The objective of this study was to compare the tear strengths of non-processed and processed ethylene vinyl acetate (EVA) specimens in various thicknesses.

Material and Method

The mouthgurad material used in this study was Ethylene Vinyl Acetate **(**EVA) (Bioplast®, Scheu Dental GmbH, Iserlohn, Germany) in three different thicknesses; 3 mm, 4 mm and 5 mm. Twelve specimens in each thickness were fabricated from non-processed and processed EVA sheet. The specimen's grouping is illustrated in Fig.1.

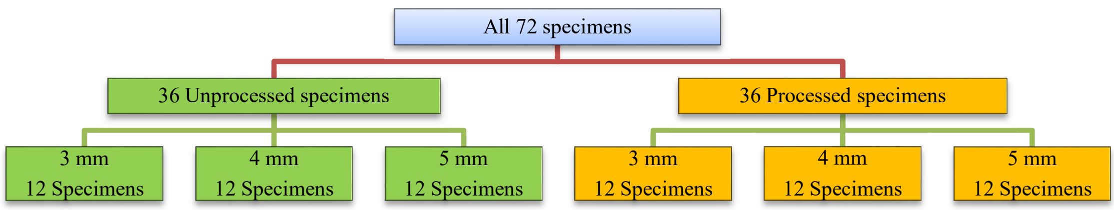

Fig. 1 The diagram of specimen number and grouping

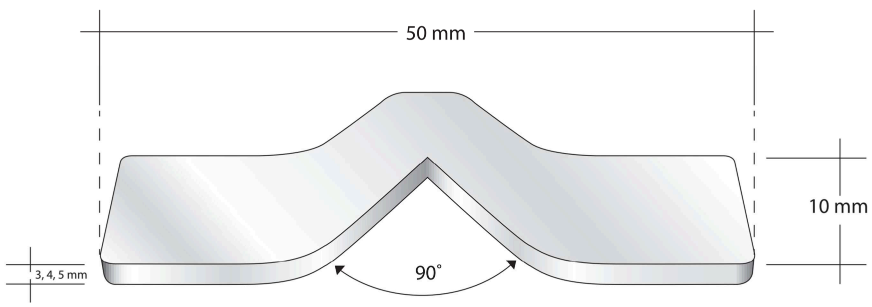

Fig. 2 The schematic diagram illustrating the tear strength specimen

Specimen Preparation

To fabricate the processed specimens, EVA sheets were formed on the cylinder-shaped stone model (Whip Mix, USA) diameter 10 cm and 5 mm in thickness by using the pressure-molding device (Biostar® Scheu Dental GmbH, Iserlohn, Germany). According to the manufacturer recommendation, The temperature for all EVA sheet were 220 (°C). The heating and cooling time for 3, 4 and 5 mm. EVA sheet were 60, 70, 90 seconds and 120,180,200 seconds, accordingly. These parameter were achieved by scanning the barcode printed on each EVA sheet.

The custom made metal block used for specimens cutting was modified from the ASTM D624-00 guideline [13]. Both the non-processed and processed EVA sheet were cut by putting the EVA sheet under the custom made metal block and pressing machine (Howa Sangyo milling machine, model: STM-2V, serial: 45011, Osaka, Japan). The sizes and margins of all specimens were evaluated.

The tear strength specimens were prepared in elongated squares end shapes and a centrally located offset 90° right angle width 6 mm as shown in Fig.2. The thicknesses of the non-processed and processed specimens were measured with digital caliper (Super Caliper Series 500, Mitutoyo America Corporation. USA).

Tear strength measurement

The tear strength measurements were conducted according to the guideline by ASTM D 624-00 [13], by using the Universal testing machine (LLOYD 1K series AMETEK, Inc. UK) at a constant crosshead speed of 500 mm/min. The results of tear resistance were presented by the minimum force requiring for completely breakdown of the specimen (N/mm) as shown in Eq.1.

$$\mathbf{Ts} = \frac{\mathbf{F}}{\mathbf{t}} \quad (1)$$

T_s = tear resistance (N/mm)

F = force to tear specimen (N)

t = thickness of specimen (mm)

Statistical analysis

Mean and standard deviation of tear strengths were tested for a normal distribution by using Kolmogorov-Smirnov test (K-S test). Levene’s test was used to check homogeneity of variant. Independent T-test was used to test the tear strengths of non-processed and processed EVA specimens in each thickness. One-way ANOVA was used to test the differences in tear strength of non-processed and processed EVA sheets in three different thicknesses**.**

Results

The Kolmogorov-Smirnov test revealed that the data was normally distributed and Levene's test revealed homogeneity of variances. The mean thicknesses and the standard deviations of non-processed and processed EVA specimens in each thickness are shown in Table 1. The mean tear strength and the standard deviation of non-processed and processed EVA specimens in each thickness are shown in the Fig.3. The mean tear strengths of processed EVA specimens were significant lower than the non-processed EVA specimens in all thicknesses tested ($P \leq 0.05$). There were no significant differences in the mean tear strength of EVA specimens among different thicknesses in both non-processed and processed groups.

Table 1 The mean thicknesses and the standard deviations of non-processed and processed EVA specimens

Manufacturer thickness[mm]	Thickness of non-processed specimens [mm]		Thickness of processed specimens [mm]	
	Mean	SD	Mean	SD
3	2.97	0.01	2.79	0.09
4	4.09	0.02	3.79	0.12
5	4.80	0.01	4.44	0.09

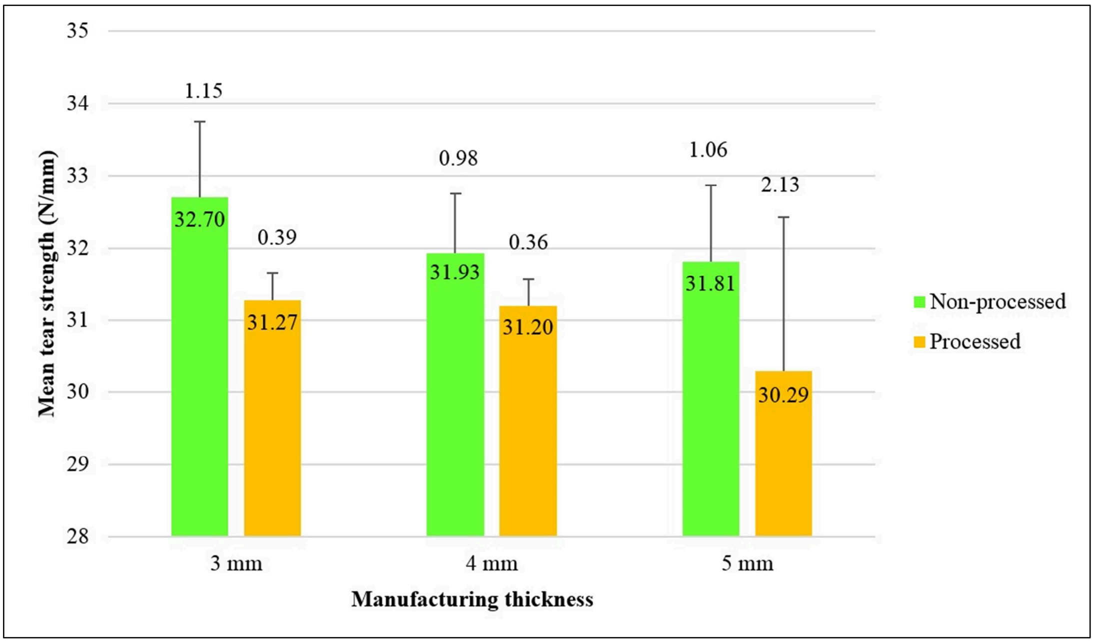

Fig. 3 The bar graph showing the mean tear strength and the standard deviation of non-processed and processed EVA specimens

Discussion

EVA mouthguard material can be categorized as thermoplastic polymers. The physical and mechanical properties of EVA mouthgurad material are influenced by changes in temperature, environment, composition structure, and the molecular weight of the polymer [14].

The effect of thermoforming on properties the energy absorbing capacity of mouthguard material has been investigated in one study [15]. It was found that the processed sample had superior energy absorbing capacity than the unprocessed samples. The author suggested that it could be the result of releasing of manufacturing stresses by the thermoforming. On the other hand, some studies reported that the thinning of the mouthguard material after thermoforming can compromise its protective ability of the moutguad [16-17].

There have been some studies focusing in determining the tear strength of mouthgurad material [9-12]. All of the studies used non-processed mouthguard material. The reported tear strength values were ranging from 21-56.5 N/mm. The mean tear strength of non-processed group from the present study was in the comparable range of those studies. Among these studies, one study used EVA mouthguard material (Bioplast®) which was also used in this study [9]. The reported tear strength value of non-processed EVA material from that study was 35 N/mm. which is comparable to the result of the present study.

The discrepancies of the tear strength from the present study and those studies may be resulted from the notch width dimension of the specimen and the variation in the composition of mouthguard material. Thus, within-study comparisons are the most suitable.

Significant difference in thickness at the anterior teeth and the molar region of final mouthgaurd fabricated by vacuum-forming process and pressure-forming process has been reported [7]. Thus, the present study used the pressure-forming process to form the mouthguard in order to minimize the variation resulted from the vacuum–forming process such as heating condition, holding condition etc. [18-20].

In real circumstance, mouthguard will undergo deformed after the action force reach the yield point and readily to be discarded by the user. Thus, the more useful measurement should be the maximum stress at yield point rather that the maximum stress at rupture.

It is more clinical relevant for testing properties of the processed mouthguard than testing only the mouthguard material before processing. Moreover, to simulate the actual mouthguard fabrication, the reported physical properties of the mouthguard material which was formed on the dental cast are useful than those obtained from the cylindrical-shaped stone model. The lack of the information of tear strength value of mouthguard material after thermoforming on the dental cast could be resulted from the dimension of the tear strength specimen dimension. It is challenging to fabricate the tear strength specimen which has flat surface form the mouthguard material formed on the dental cast.

Conclusion

The tear strength of mouthgurad after thermoforming has not been documented. This study compared the tear strength of processed and non-processed EVA mouthguard material. It was found that the thermoforming process has the significant effect on the decreased tear strength of the EVA mouthguard material formed by pressure molding device (Biostar®) in all thicknesses. In the real circumstance, mouthguard material can be exploited only after thermoforming on dental cast. Thus, it is necessity and more clinical relevant for testing properties of the processed mouthguard material than testing only the mouthguard material before processing.

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