Original Research Article

Comparison of Tensile Strength of 3 Different Thermoplastic Sheets Used In Orthodontic Aligners

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Abstract

Objective: This study aims to assess and compare the tensile strength of three different thermoplastic sheets that are used in orthodontic aligners.

Materials and Methods: Three thermoplastic materials with a thickness of 0.8 mm were used. Values of tensile strength were obtained using Universal tensile tester machine (Model – DTRX-20 KN) at room temperature.

Results: The tensile strength values were highest for Group I sheets followed by Group II sheets and Group III sheets. This illustrates greater fracture resistance of the Group I sheet while comparing it with Group II and Group III.

Conclusion: Group I had better properties amongst the thermoplastic sheets compared in terms of tensile strength and elongation.

Keywords: Clear aligner, Tensile strength, Universal tensile tester

Introduction

The clear aligner market has experienced exponential expansion because of the rising desire for discreet, aesthetically pleasing orthodontics.[1] A vast array of appliances with varying mechanisms of operation, construction techniques, and suitability for different malocclusion therapies is included in Clear Aligner Therapy.[2] An aligner, or thermoplastic appliance, is constructed using a single setup model that mirrors each phase.[3]

In orthodontics, the aim of moving the teeth to the desired position is achieved by a consistent force on the periodontal membrane. The basis of this force is usually a deflected spring or archwire and in residual supports of the basis force is a thermoplastic sheet. This force should be such that it reduces the likelihood of dislodging the tissue, interfering with absorption and other effects.

The first aligner products marketed by the multinational Align Technology (San Jose, CA) were fabricated from a rigid polyurethane layer derived from methylene diphenyl diisocyanate and 1,6-hexanediol. The next changes were designed by Exceed-30 (Alignment Technology) to be flexible, unbreakable and transparent. In 2012, the technology was replaced by SmartTrack (Alignment Technology), a thermoplastic polyurethane. According to the company should be able to meet the needs for lighter, more constant force and better flexibility and provide predictable orthodontic tooth movement.[4]

Clear aligner treatment covers a variety of aligners with different action, structure and suitability for the treatment of various malocclusions. Recently, the system has evolved with the introduction of attachment materials, and more efficient products, allowing more movement in less time.[5]

Tensile strength is defined as the maximum stress that the sample can withstand before rupture. Clear aligners are viscoelastic and have properties between viscous and elastic. This means that their behavior under load may change over time, even initially and before tooth movement is complete.[6]

Kohda et al.[7] compared the elastic modulus and hardness of three different aligner materials and found that these factors affect the force system of aligners.

The aim of the present study was to compare tensile strength of three different thermoplastic sheets that are used in orthodontic aligners.

Material And Method

The following three sheets were used in the study:

Group I: 0.8mm * 125mm Sheet made of Polyurethane (PU)

Group II: 0.8mm * 125mm Sheet made of Polyethylene terephthalate glycol (PETG) and Polyurethane (PU)

Group III: 0.8mm * 125mm Sheet made from Polyethylene terephthalate glycol (PETG)

Armamentarium

Figure 1 : Universal Testing Machine

Universal tensile tester machine (Model – DTRX-20 KN) (Figure 1).

Inclusion criteria

Thermoplastic sheets of 0.8mm * 125mm.

Exclusion criteria

Sheets with thicknesses of 0.6mm or 1mm were excluded.

Method

Twenty samples were used from each group for testing. All the sheets were thermoformed and tested under similar conditions at room temperature.

A standard tensile test with each thermoplastic sheet from three groups was performed in the Universal Tensile Tester Machine (DTRX-20KN). All the thermoplastic sheets were cut to a dimension of 15mm as per the guidelines of ASTM D 882. A load of 768N, 644N and 533N for the three groups (I, II, III) respectively was set in the machine and crosshead speed was 100mm per minute till the thermoplastic sheet was fractured.

The UTS value is obtained by dividing the load required to break the thermoplastic sheet by the cross-sectional area of the thermoplastic sheet. Tensile strength (N/mm^2) and standard deviation are calculated. (Figure 2)

Figure 2 : Thermoplastic Sheet Specimen Being Tested For Tensile Strength

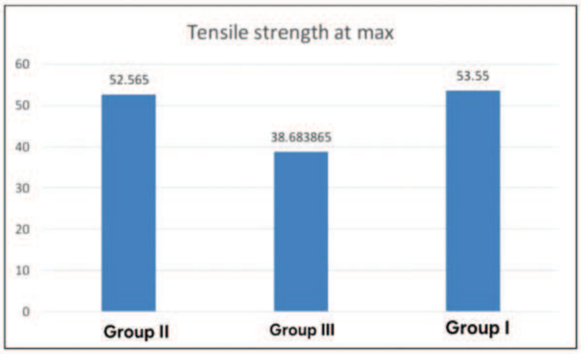
Result

One-way ANOVA test was used to compare the statistically significant mean differences between the tensile strength and maximum elongation of Group I, Group II & Group III sheets.

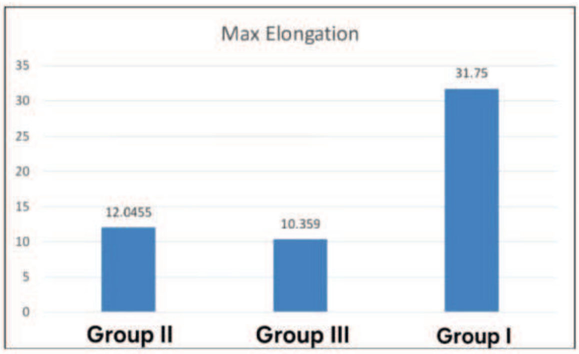
Whereas the Posthoc Tukey test is used to assess the significance of differences between pairs of groups that is Group II vs Group III, Group II vs Group I and Group III vs Group I.

The mean values of maximum elongation obtained for Group I, Group II and Group III were 31.75±1.74 N/mm2, 12.05±0.55 N/mm2 and 10.36±1.06 N/mm2 respectively. The range was from 28.80 – 34.20 N/mm2 for Group I, 11.0-12.9 N/mm2 for Group II and 8.90 – 11.78 N/mm2 for Group III.

The mean values of tensile strength obtained for Group I, Group II and Group III were 53.55±0.6 N/mm2, 52.57±0.29 N/mm2 and 38.68±0.76 N/mm2 respectively. The range was from 52.02 – 54.33 N/mm2 for Group I, 52.02 – 53.19 N/mm2 for Group II and 38.02 – 39.67 N/mm2 for Group III. Graph 1 and Graph 2 compare the Tensile Strength and Maximum Elongation respectively for the three



Graph 1 : Comparison of Tensile Strength of Group I, Group II & Group III Sheets



Graph 2 : Comparison of Maximum Elongation of Group I, Group II & Group III Sheets

thermoplastic sheets used, which states that both the values are maximum for Group I sheets followed by Group II and Group III.

Discussion

The physical and mechanical properties of thermoplastic materials used to manufacture clear aligners should be evaluated after thermoforming to characterize their properties for clinical use.[8] Tensile tests were performed to gain a basic understanding of typical tensile properties including elastic modulus. Tensile testing was performed using an Instron Universal testing machine. Tensile tests, in which the entire thermoplastic sheet is stretched to its elastic limit, are recommended to evaluate the stress-strain behavior.

While comparing the values for these using ANOVA and Posthoc Tukey tests, the P value was highly significant due to the considerable differences between Group I – Group III and between Group III – Group II and between Group I – Group II (**Table 1**).

	Tensile Strength at max	Max Elongation
Group II (N=20) Mean ±SD	52.57±0.29	12.05±0.55
Group III (N=20) Mean ±SD	.68±0.76	10.36±1.06
Group I (N=20) Mean ±SD	.55±0.6	31.75±1.74
F/Welch Statistics (* represents Welch test)	91.434*	1222.797*
Group II vs Group III difference (p-value)	.88(<0.001)	1.69(<0.001)
Group II v/s Group I difference (p-value)	-0.99(<0.001)	-19.7(<0.001)
Group III v/s Group I difference (p-value)	-14.87(<0.001)	-21.39(<0.001)

Table 1: Comparison of mean maximum elongation and mean tensile strength of Group I, Group II and Group III sheets using One-way ANOVA test and POST HOC TUCKEY test

Thus, upon evaluation of tensile strength, Group I was the strongest amongst them with the highest values for the tensile strength followed by Group II serving as an intermediate strength and Group III having the lowest values amongst the three thermoplastic sheets tested. Upon evaluation of maximum elongation, Group II was the strongest amongst them with the highest values for the maximum elongation followed by Group II serving as an intermediate strength and Group III having the lowest values amongst the three thermoplastic sheets tested. Maximum elongation for Group III was almost half the value of Group I sheets. The increase in the tensile strength value for Group I implies greater fracture strength.

To design a reliable and effective orthodontic treatment, materials should be selected after determining their mechanical properties.[9] Thermoplastics with higher yield strength, ultimate tensile strength, and toughness are desirable for making clear aligners.

Ahm *et al* investigated the tensile strength of three-layer transparent alignments with stacks of different layers at room temperature. The highest tensile strength was obtained with a 3-layer transparent aligner (469 N), followed by 2-layer (317 N) and single layer (258 N). Based on this study, the 3-layer transparent aligner appears to have the best mechanical performance, but the lack of aging results limits to evaluate of a positive effect of the 3-layer transparent aligner on the mechanical properties of this new design.[10] In the present study, a single-layer thermoplastic sheet was used and the obtained results showed significant differences.

Papadopoulos *et al* investigated the mechanical properties of Invisalign aligners after intraoral aging. According to these authors, various factors may be responsible for the deterioration of the mechanical properties of aligners after oral consumption. The first can be due to the material itself. [11]

Ruy *et al* investigated the effects of thermoforming on the physical and mechanical properties of transparent aligners. They observed that the optical transparency, tensile strength, and elastic modulus of the alignment materials decreased after the thermoforming process, while water absorption increased.[12]

Yan sing Ma *et al* characterized and compared the tensile properties of PC 2858 and PETG after multiproportional mixing, determined the appropriate mixing ratio of the new thermoplastic, and compared its mechanical performance with commercial thermoplastics. In terms of long-term tensile properties, PETG/PC2858 showed the lowest stress relaxation of 0.0005 ± 0.0080 N/s, which was slightly better than PETG sheets, but not significantly.[13]

Conclusion

The following conclusions were derived:

1. The tensile strength values were highest for Group I sheets.

2. Tensile strength values for Group II sheets were comparatively higher than Group III sheets but lower than Group I sheets.

3. The Group III sheets had the least values for tensile strength.

4. The elevated UTS value for Group I illustrates that it would have superior fracture resistance, thus triumphing over a main shortcoming of Group III.

5. Maximum elongation was seen with Group I sheets.

6. Elongation for Group II sheets comparatively more than Group III sheets but less than Group I sheets.

7. Group III sheets had the minimal elongation.

8. This illustrates greater resiliency of the Group I sheet while comparing with Group II and Group III.

Therefore, from our study, we derive the inference that GROUP I had better properties amongst the thermoplastic sheets compared in terms of tensile strength

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