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CONSTRUCTION OF ORTHODONTIC APPLIANCES USING LAYERING TECHNOLOGIES[3]

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Abstract: *This study describes a technological method for the construction of orthodontic brackets using digital layering technologies (Stereolithography) and photopolymer resigns. A comparison is made with modern conventional technologies for their production. The resulting properties of these devices have been investigated in terms of their mechanical properties and their optical characteristics, which are important for their functionality and aesthetic appearance.*

Keywords: *Materials in dentistry, Orthodontics*

INTRODUCTION

Orthodontics is one of the most studied subject in the dental medicine and it involves a treatment for the correction of irregularly aligned teeth, usually involving braces, aligners and sometimes oral surgery (Baroda Dental Clinic, 2022), (Siliguri W.B. et al., 2020). Over the course of the patient’s treatment the dentists will swap the existing aligners for new ones. Each aligner is designed to get the teeth in place for the next phase as long as the patient wears the aligners for the recommended 22 hours per day. The set of such devices will differ by their thickness and rigidity. Thus we have to have relevant information about the mechanical properties and the aesthetic appearance of the aligners.

In general these apparatus (aligners) must meet a number of requirements such as: (i) be made of transparent and aesthetic polymer, (ii) the material is curable, (iii) have biocompatible properties,

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(iv) be stable at body temperature, (v) possess sufficiently high mechanical properties (stiffness) to resist occlusal (chewing) forces, (vi) not deteriorate over time.

Of the mandatory requirements thus listed (especially when treating children), the aesthetic properties which are function of its transparency and the mechanical properties such as stiffness and rigidity are of a primarily importance.

In this study, we compare (i) an innovative ("digital") aligner manufacturing technology using DLP-SLA (Digital Light Projector, Stereolytography technology (Todorov G., Kamberov K., 2015), (Ratner B. et al., 2004), (R. Minev, E. Minev, 2016), (E.Minev et al, 2015) NextDent OrthoFlex with (ii) a "traditional" polymer folio forming technology.

The SLA OrthoFlex is transparent class 2a biocompatible photo polymerizing material developed for the production of 3D printed occlusal splints and retainers. It has (Vartex – Dntal B.V., Soesterberg, Netherlands, 2022) a strength of 67MPa, modulus of elasticity - 1721MPa and Charpy strength 15 kJ/mm^2.

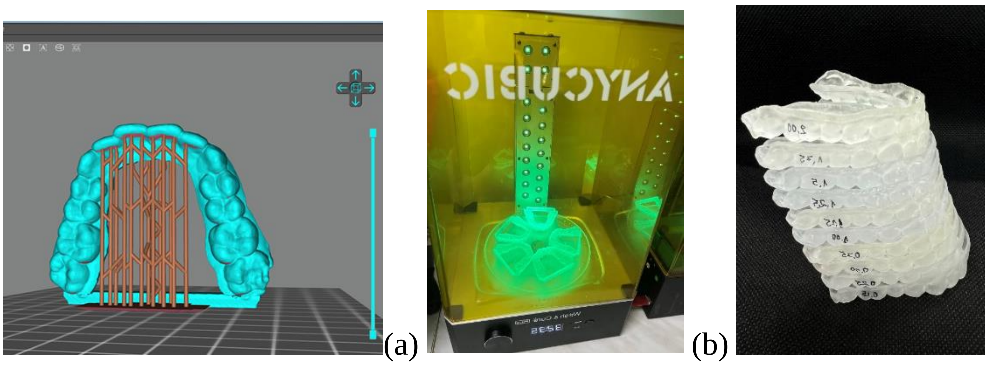
EXPOSITION

Description of the construction experiments

The first researched process chain ("conventional" technology) represents the traditional method covering the following stages: generating a model; vacuum moulding of the aligners. The production of the ceramic model can be carried out in two ways: (i) scanning of the tooth profiles and production of the model by layer-by-layer 3D technology; (ii) taking a replica of the patient's dental profile. In our study, the second approach was used.

The second researched process chain ("digital" technology with 3D printing) includes the following stages: (i) scanning of the dental profile and preparation of a 3D digital model; (ii) layer-by-layer construction of the aligner using a 3D printer (DLP SLA).

In the digital technology study, an impression was initially scanned from a patient with a "Comphort + intraoral" scanner into an STL file, which was transferred to a CAD/CAM system in order to modify the resulting shell shape in thickness. The files are then fed to the control CAM program for "layer-by-layer slicing" and determining the current sections to build. In the study, 10 aligners with different thicknesses from 0.15 to 2.0 mm were made (Fig.1). The build was carried out with the following parameters optimized and recommended by the 3D printer manufacturer: speed along Z axis - 23 mm/h; 5 min - mixing before print; drying - 10 min; post cure - 30 min; print inclination 80˚-90˚; base - 3 mm; supports -1.5 mm; washing 3 min in ethanol; fan drying - 2 min.



(a) (b) (c)

Fig. 1 Building the aligners: (a) CAD preparation; (b) part build; (c) the set of aligners.

Methodology for the transparency research

This property is important for aesthetic reasons, which is why the question arises as to how thickness affects it. The transparency of orthodontic aligners with thicknesses in the range 0.15mm-

2.00mm was investigated. The experiments were carried out according to the scheme of Fig. 2, where light with an illumination of 400 Lux is passed through the manufactured aligners and the illuminance or luminous flux per unit area, Lux is measured after passing through them.

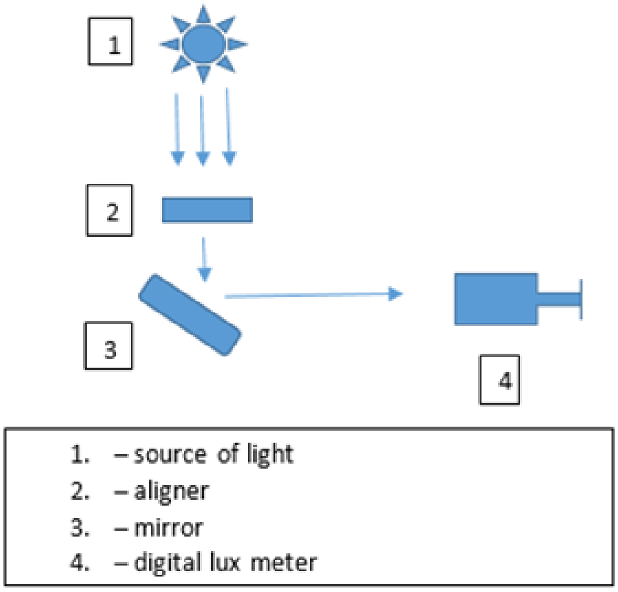


Fig.2 Set-up for studying the transparency

Study of the mechanical characteristics

The behavior of the aligners under tension and pressure was investigated (Fig.3) by taking the load-displacement curves and calculating the stiffness K=F/Δl as a function of sample thickness d, mm. The deformation rate of 1 mm/min was applied and an INSTRON 3384 universal testing machine was used in the +/-0.05N force and +/-5μm displacement accuracy mode. The statistical error in determining the stiffness of the studied samples was within 12%.

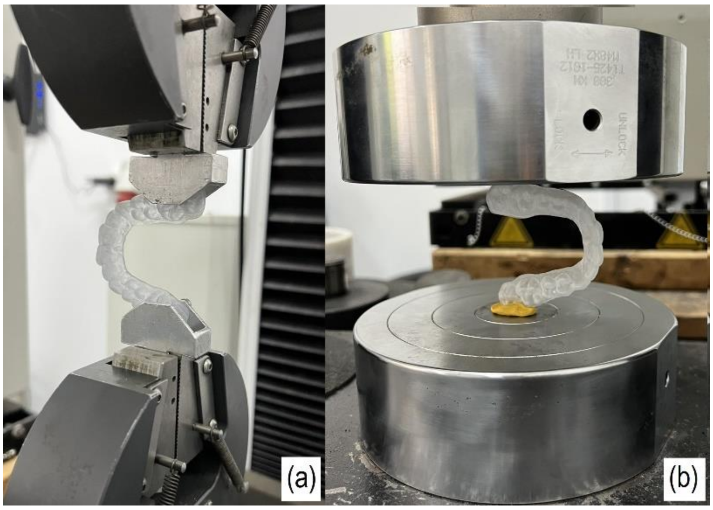


Fig.3 Testing of the samples: (a) – tension; (b) – compression.

Experimental results and analyses - transparency study

The results of the transparency study as function of the thickness of the aligners are presented in Fig.4. It can be seen that the light intensity loss varies from 3% for the samples with 0.15-0.5 mm thickness to 12% for the samples with thicknesses up to 2mm.

The dependence of the transparency on the thickness can be assumed to be linear and its change can be calculated by the empirical formula: %ΔI = 2.5 + 5.5 d (d, mm).

It can be concluded that within the studied thicknesses, the optical qualities of the 3D printed devices do not change significantly. For thicknesses up to 1.0 mm, this change is insignificant, and for greater thicknesses, this change does not unacceptably disturb the aesthetic qualities of the product.

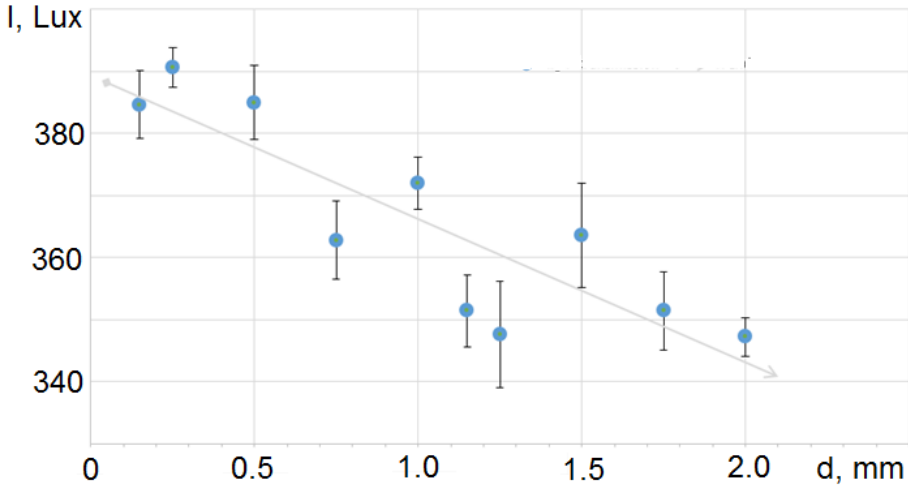


Fig.4 Transparency of aligners of different thicknesses (d, mm). The illuminance (I, Lux) of the light passing through them was measured.

The difference in the transparency of aligners made by conventional technology and 3D printing is insignificant. Up to a thickness of 1 mm, this difference is below 1%, and for thicknesses over 1 mm, it reaches 5%, but it is compatible with the statistical error of the measurement (3..4%).

Experimental results and analyses - mechanical characteristics investigation

The deformation curves of the studied devices are presented in Fig.5. They were taken in a range of 5 mm maximum compressive/tensile deformation and show the following features:

1).Increasing the thickness of the aligners leads to a significant increase (up to about 70%) of the forces required to realize the same deformation (e.g. 5 mm). For compressive loads, these differences are in the range of 2N-7N, and for tensile loads in the range of 6N-19N.

2).The stiffness ($K=F/\Delta l$) of the aligners changes within the limits K_{comp} = 0.05-0.2 in compression and K_{tens} = 0.3-0.8 in tension. I.e. the orthodontic structure shows about 4 times greater stiffness in tension than in compression. It should be noted that occlusal deformations (jaw closure and masticatory movements) occurring in aligners are expected to be mainly tensile, making thickness variation an effective factor in determining the orthodontic appliance set. The K_{comp} and K_{tens} change with thickness (d) variation can be distinguished in three ranges (Table 1) probably due to the stress state change from a more pronounced plane-stressed to a bulk-stressed state.

The stresses occurring in the most loaded section (in the middle of the aligner, attached to the “dentes incisive”) can be roughly calculated, starting from the simplification that it is loaded in pure compression/tension (at 5 mm compression/tension deformation) and they amount to about 0.2 MPa at pressure and 0.5 MPa in tension (in aligners with d = 1.0 mm).

The comparison of the deformation diagrams of aligners manufactured by the "traditional" and "digital" technologies (Fig.6) shows that at smaller thicknesses (d<1.0mm) the aligners manufactured by SLA technology have about twice the stiffness of those produced by traditional technology (by forming). For thicker devices, the stiffness is practically the same.

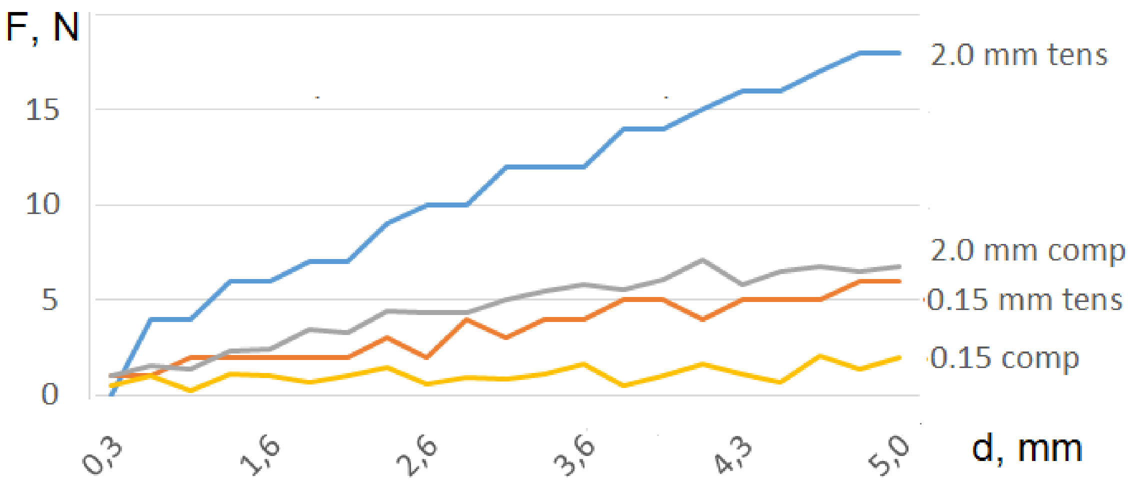
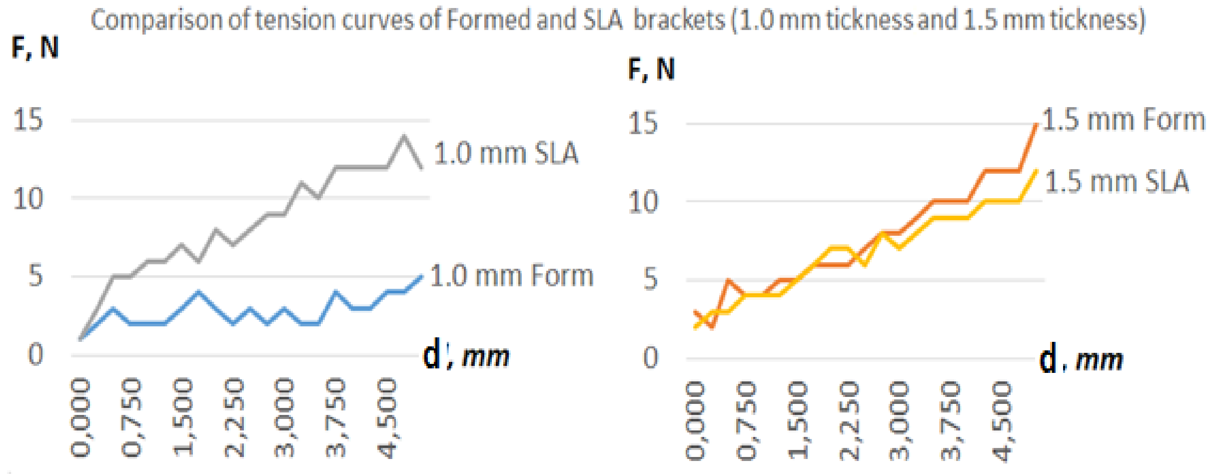


Fig.5 Deformation diagrams of pressure and tension of aligners with minimum (0.15 mm) and maximum (2.0 mm) thicknesses

Table 1 Values of the stiffness coefficient (K= F/Δl, N/mm) of aligners with different thickness (d)

d, mm	0.15 – 0.5	0,75 – 1.5	1.75 – 2.0
Tension	0.3	0.6	0.8
Compression	0.05	0.1	0.2



(a) (b)

Fig.6 Deformation diagrams of 1.0 mm (a) and 1.5 mm (b) aligners produced by moulding (traditional technology - Forming) and digital technology (SLA).

CONCLUSIONS

The following more important conclusions can be drawn from the research:

1).The orthodontic devices produced by layering digital technology (DLP SLA) are not inferior to conventional ones in terms of both mechanical and optical (aesthetic) properties. They show the same or up to twice greater stiffness (for thicknesses of 1-2 mm). Their transparency is practically the same as that of mold devices.

2).The stiffness of orthodontic devices (aligners) is strongly dependent on thickness and can be controlled by using the resulting deformation curves. They show an increase of up to 70% in the forces required to deform the aligner depending on its thickness. The stiffness of the devices measured by the coefficient ($K=F/\Delta l$) changes about 4 times when the thickness increases from 0.15 to 2 mm. This makes it possible to plan to use a set of aligners of different thickness to achieve progressive corrective results during the course of treatment.

Acknowledgments

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