

ASPECTS CONCERNING THE ELASTIC PROPERTIES OF THE ALIGNER MATERIALS

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ABSTRACT

Aim of the study The demand for clear aligners therapy has increased significantly in recent times, due to awareness of aesthetic orthodontic treatment alternatives and the materials used in aligners technology need to be improved by their properties - one of the most essential aspects. **Materials and methods** Our study aimed to determine the important property of elasticity of different types of materials used in the manufacture of aligners, usually made either through the thermoforming process or 3D printing, with a performant testing system, a specific software, on samples made from different materials and different thickness, with special marks, in order to determine the elasticity until the breaking moment. Data were registered and the software elaborated the parameters and the curves for specific elastic range, and the variations of relaxation in relation to the longitudinal and transversal specific deformation. **Conclusions** The study revealed that there were no significant longitudinal specific deformation of approx. 1%, of the variation graph, correlating the results with similar findings in the scientific literature.

Key words: elasticity, aligner materials, specific deformation

INTRODUCTION

The demand for clear aligners therapy has increased significantly in recent times, due to awareness of aesthetic orthodontic treatment alternatives, especially for adult patients [1], as well as the widespread use of various social media channels, due to marketing by the well-known companies that produce these devices. Clear aligner therapy (CAT), introduced as a modern alternative to conventional fixed appliances for correcting dental malalignments, including transverse malocclusions, was first conceptualised by Kesling in 1946.

Initially, orthodontists were hesitant to recommend CAT for treating complex malocclusions, such as correcting buccolingual inclination and closing extraction spaces. [2]

Clear aligners created through computer-aided design/computer-aided manufacturing (CAD-CAM) systems are removable orthodontic devices designed to facilitate tooth movement. Improvements in biomechanics have enabled the treatment of more complex malocclusions, including class II, class III, and extraction cases. Crowding can be addressed by using clear

aligners for proclining the teeth, expanding the dental arch, performing an IPR, or extracting teeth in more severe cases. [3]

The composition of the material utilized for the fabrication of a clear aligner influences the clinical performance of the aligners [4, 5] and this composition in turn is influenced by the actual manufacturing process that can basically be divided into two categories: the conventional method of vacuum thermoforming with thermoplastic material moulding on physical models and the other category of direct 3D printing without intermediary physical models [6,7].

Clear aligner materials have evolved from single-layered or monophasic, to second-generation polyurethane materials, to the currently used third-generation multilayered materials that often comprise hard and soft layers. While the soft layer imparts the property of elastic deformation allowing smooth seating of the aligner, the hard layer ensures strength and durability [8]. Clear aligners materials are available in a variety of thicknesses, ranging from 0.50 mm to 1.5 mm, and derivatives of polyvinyl chloride, polyethylene-terephthalate glycol (PET-G), polypropylene (PP), polycarbonate (PC), thermoplastic polyurethanes (TPU), ethylene-vinyl acetate (EVA) and many more (Lombardo et al., 2015). [9] The most commonly used materials in aligners are polyurethane and glycol-modified PET. Polyurethane sheet is the most suitable option; the polymer type material is formed from isocyanate with a polyol in the presence of catalyst and some additives.

Although the clinical efficacy of clear aligners can be affected by a multitude of factors [10–14], the properties of materials used for their fabrication remain one of the most essential aspects in determining their

mechanical and clinical features [15].

MATERIALS AND METHODS

Our study aimed to determine the important property of elasticity of different types of materials used in the manufacture of aligners, usually made either through the thermoforming process or 3D printing.

Figure 1 shows an overview during the tests in the elastic domain, with the acquisition of data in PC files from the strain gauges longitudinally and transversely fixed, by means of the Vishay P3 strain gauge. Thus, the equipment used in these determinations were: the Instron testing machine, the PC of the testing machine with the software and method related to these types of tests, the Vishay P3 strain gauge and the PC that monitors the Strain Gauge, and on which acquire the obtained data. All this equipment is in figure 1 - the system was Instron® type (INSTRON - MODEL 34SC-5; USA). (Department of Strength of Materials, Faculty of Mechanics, Gheorghe Asachi University, Iași)



Fig.1. The system used for elasticity tests

The extensometer shown in figure 2 was mounted on the 11 samples tested until

failure, in order to acquire the data with the help of which the longitudinal specific deformation is calculated. The distance between the arms of the extensometer was 12.5 mm, the sample was clamped with rubber elastic bands. Moreover, although it is recommended to use the extensometer only in the elastic zone for a more accurate determination of the longitudinal modulus of elasticity, the acquisition of data from it was done throughout the test until the samples broke. This could be done because, as will be seen from the figures showing the specific stress-strain curve, the latter, for the samples of the studied material, was not large for the extensometer to leave the safety zone (4.8 mm).

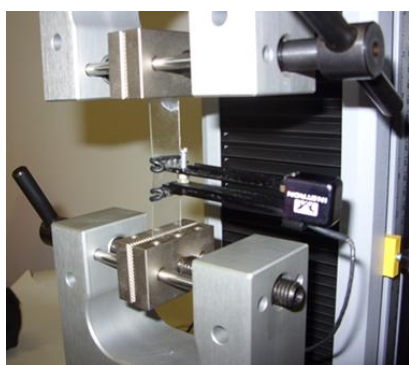


Fig. 2. The extensometer with the sample

Data acquisition and processing were performed using the integrated Instron Bluehill® software, Figure 3, which meets the needs of a wide range of applications, including plastics, metals, elastomers, adhesives, and others.



Fig. 3. BlueHill software installed on the computer testing system

An image of the initial samples, with the protective foil, before stressing can be seen in figure 4. From the initial circular shape, given the dimensions required for the samples (the need to be clamped in the jaws of the testing machine, etc.), only two flat samples like those in figure 4 could be cut and processed.

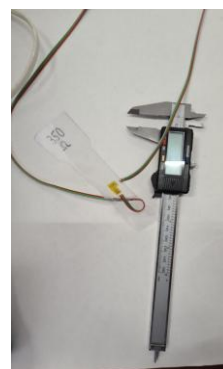


Fig. 4. Sample cut, measured and processed from the initial circular shape

The samples were cut into parallelepiped shapes, after which, by milling at low cutting parameters and with emulsion jet cooling, they were given the shape with a calibrated portion of 16 x 54 mmp. The wider area at the ends was fixed and the calibrated portion is necessary for obtaining the break here, for mounting the extensometer and, respectively, for gluing the strain gauge marks.

On the 11 samples stressed to failure, for the acquisition of data with which the specific longitudinal deformation can be calculated, as the extensometer was mounted (figure 5).

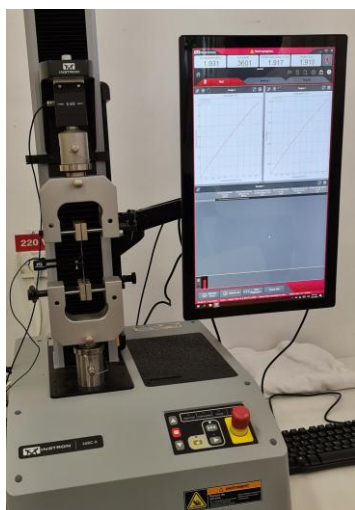


Fig. 5. Testing the samples with the extensometer on the Instron machine

RESULTS AND DISCUSSIONS

On the sample made from one of the 0.8 mm discs two tensometric marks (electro-tensometric transducers) were fixed, one with the grid oriented in the longitudinal direction and the other in the transverse direction of the sample; both brands directly measure the specific deformations in mentioned directions.

Figure 6 shows the variation of the tension in relation to the specific longitudinal linear deformation, the latter calculated with displacement values taken from the sensor of the loading machine.

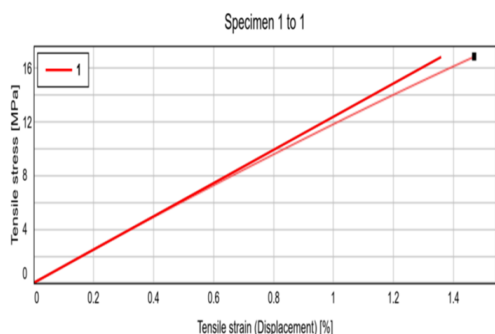


Fig. 6. Specific stress-strain curve for the sample with a thickness of 0.8 mm with tensometric marks requested in the elastic domain

In addition to this difference, it should be noted that the specific deformations are expressed differently: in figure 6 in [%] while in figure 7 in [$\mu\epsilon$], respectively, the value obtained from the tensometric bridge multiplied by 10^{-6} . In any case, the slope of the approximation line in figure 5.16 represents the longitudinal modulus of elasticity, which is 2360.8 MPa, having the calculation relationship:

$$E = \Delta\sigma / \Delta\epsilon$$

where $\Delta\sigma$ is the stress variation on the linear area and $\Delta\epsilon$ is the variation of the specific longitudinal linear strain on the linear portion of the variation.

There is not really a significant difference between this value and the one automatically provided by the test machine, namely 2042.89 MPa.

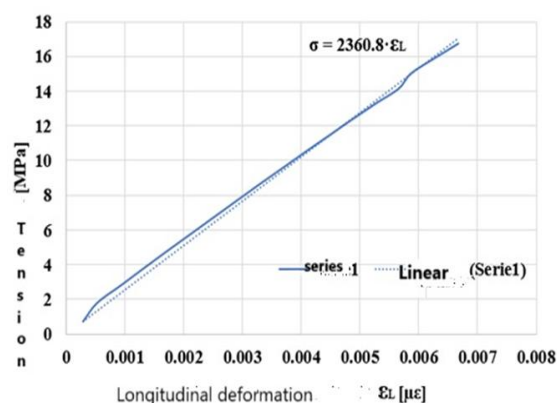


Fig. 7. Longitudinal specific stress-strain curve for the sample with marks - 0.8 mm

In figure 8, the variation of the longitudinal specific linear deformation in relation to the transverse one is presented. The data are taken exclusively from the tensometric marks fixed on the sample. It is considered that the ratio between the two previously specified deformations represents the characteristic called Poisson's ratio, respectively:

$$\nu = \epsilon_T / \epsilon_L$$

where ϵ_L is the specific strain measured by the strain gauge affixed to the longitudinal

grid on the specimen while ϵ_T is the specific strain measured by the strain gauge affixed to the transverse grid on the specimen.

Consequently, the coefficient in the relation given in figure 8, which represents the relation of the approximation line of the variation $\epsilon_T - \epsilon_L$, will be precisely Poisson's coefficient. So, the Poisson's ratio for the 0.8 mm thick material is 0.3872.

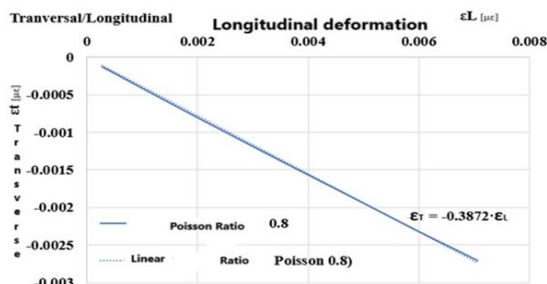


Fig. 8. The transverse specific deformation - longitudinal specific deformation curve for the sample with marks

In figure 9, for sample with 0,5 mm (a sample was made on which two strain gauges were fixed), both brands directly measure the specific deformations in the two mentioned directions.

Figure 9 shows the tension variation in relation to the specific longitudinal linear deformation, the latter calculated with displacement values taken from the loading machine sensor, while in figure 10 the same variation is shown, this time the longitudinal specific deformation being taken by to the tensometric mark glued in the longitudinal direction.

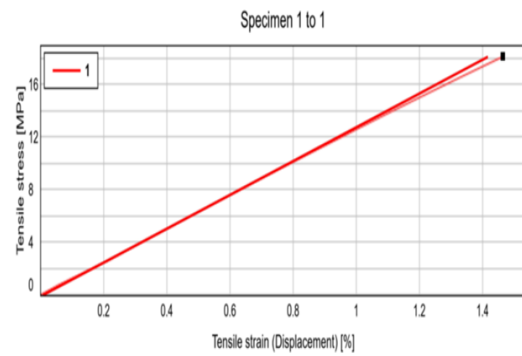


Fig. 9. Specific stress-strain curve for the sample with a thickness of 0.5 mm with tensometric marks requested in the elastic domain

In the two figures, the specific deformations are expressed differently: in figure 9 in [%] while in figure 10 in [μ ϵ], respectively, the value obtained from the tensometric bridge multiplied by 10-6.

There is no significant difference between this value and the one provided automatically by the test machine, respectively: $E= 2052.37$ MPa; Strength = 2588 MPa (figure 10). It is mentioned that the value close to the real one is the one determined based on the tensometric marks, respectively, $E= 2588$ MPa.

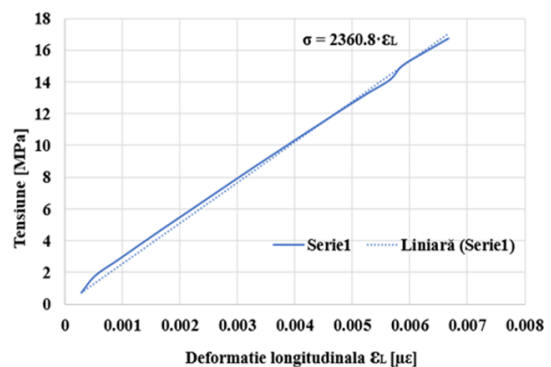


Fig. 10. Longitudinal specific stress-strain curve for the sample with marks 0.5 mm For comparison, figure 11 shows the stress variations in relation to the longitudinal specific deformation (from the longitudinal tensometric marks), obtained by the monoaxial tensile stress in the elastic

domain. It is found that the slopes of the two approximation lines have close values, the two values constituting the longitudinal elasticity models for the two types of materials/samples.

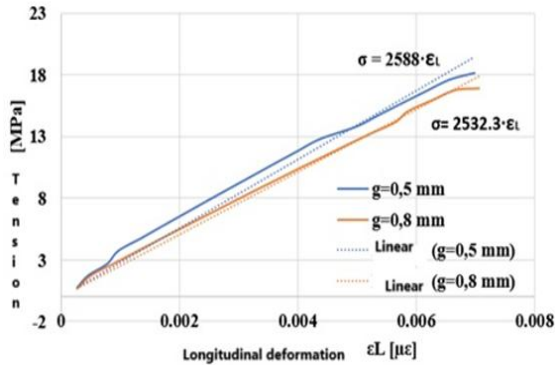


Fig. 11. Longitudinal specific variation curves for samples with marks – 0.8 mm and 0.5 mm

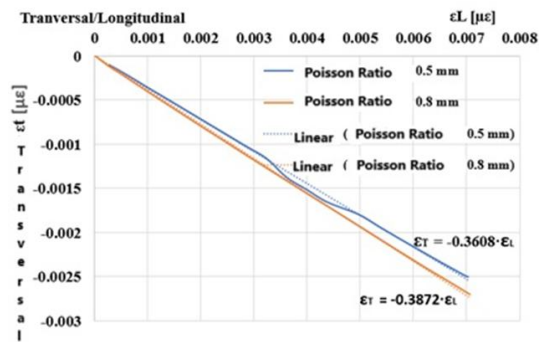


Fig. 12. The transverse specific deformation - longitudinal specific deformation curve for samples with marks – 0.8 mm and 0.5 mm

For comparison, figure 12 shows the variations of the transverse specific deformations in relation to the longitudinal specific deformation (both taken from the respective strain gauges), obtained by monoaxial traction in the elastic domain. It is found that the slopes of the two approximation lines have close values, the two values constituting the Poisson's coefficients for the two types of materials/samples.

The modulus of elasticity or Young's

modulus is a measure of the stiffness of a material and can be defined as the ratio between stress and corresponding strain. An aligner material should ideally possess adequate stiffness to exert the forces and moments needed to achieve the planned tooth movement. If the material used for aligner fabrication exhibits a very high modulus of elasticity (or high stiffness), then the resultant aligner would be very stiff leading to difficulty in aligner placement and removal for the patient. Likewise, a material with low stiffness will not be able to generate adequate forces required to move teeth [16].

Thermoplastic materials in general follow Hooke's law when subjected to forces of short duration, indicating that within the elastic limit of the stress-strain curve, when the stress is proportional to strain; the material exhibits an elastic behaviour with a return to its original size and shape on the removal of applied stress [16].

A material that can be easily deformed with minimal force can be described to possess low resiliency, as the ability to absorb energy when it is elastically "loaded" or deformed, and release that energy when "unloaded," without causing permanent deformation of the material. The measure of resiliency is the point beyond which the material undergoes some amount of permanent deformation. Unloading can be described as the measure of the force exerted by a material to move teeth [17].

When thermoplastic materials are subjected to long-term forces, they do not follow Hooke's law, and instead, exhibit 'viscoelastic' properties showing a time-dependent relationship between stress and strain [16]. Clear aligner materials are 'viscoelastic' in nature, with their properties constituting the middle ground between the properties of purely viscous and purely elastic materials. The behaviour of viscoelastic

materials can vary significantly over time when subjected to a load such as the initial placement of an aligner onto the dentition and even before any of the planned tooth movement has been initiated [18]. Multiple studies on thermoplastic polymer blending have shown that polymer blends demonstrate improved mechanical and chemical properties, eventually enhancing the clinical performances of clear aligners [19, 20–26].

CONCLUSIONS

1. A special material to manufacture the clear aligners must be a polymer with mechanical properties, resistance and elasticity and a functional resin, in order

to have a good stress relaxation and biocompatibility.

2. For comparison, our study on elasticity shows the stress variations in relation to the longitudinal specific deformation, and so, the slopes of the two approximation lines have close values - the two values constituting the longitudinal elasticity models for the two types of samples.
3. Innovations of aligner materials with shape memory combined with 3D printing technology have revealed the importance of future research to appreciate the mechanical and biological characteristics of clear aligners to further improve the treatment for each patient.

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