

Original Article

Behavior of Photopolymerizable Orthodontic Resins in Simulated Oral Conditions: A Laboratory Study

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ABSTRACT

The rapid integration of clear aligners into orthodontic practice has encouraged the advancement of biomechanical materials aimed at enhancing treatment efficiency. The mechanical behavior of these materials is a crucial factor in their clinical success and reliability. This study examines the Young's modulus of *Clear-Blokker*® (Scheu Dental), a photopolymerizable resin utilized as an attachment material for clear aligners, and analyzes its mechanical response under varying curing durations (5 s and 10 s) and environmental settings (dry storage versus immersion in artificial saliva at 37 °C). Forty-eight cylindrical samples were fabricated and tested under quasistatic compression after a 14-day period. A multifactorial analysis of variance (ANOVA) was performed at a 5% significance threshold to assess variance differences. Samples immersed in artificial saliva demonstrated a statistically significant reduction in Young's modulus compared with those stored in dry conditions ($p = 0.0213$). However, curing duration did not show a significant influence. Findings indicate that *Clear-Blokker*® exhibits mechanical behavior comparable to conventional clear aligner materials, making it a suitable adjunct for orthodontic biomechanics. Nonetheless, additional long-term clinical investigations are needed to validate its durability and effectiveness in the oral environment.

Keywords: Clear aligners, Orthodontic materials, Photopolymerizable resin, Mechanical properties

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Introduction

The use of clear aligners in orthodontics has increased dramatically over the past decade, driven by patients' preference for comfortable and aesthetic treatment options [1-3]. Clear aligners are typically composed of a sequence of transparent polymeric trays that snugly cover the teeth. They are worn continuously—except during eating and cleaning—and replaced every one to two weeks to facilitate gradual tooth movement according to the treatment plan. As their popularity has grown, technological developments have improved both the precision and versatility of aligner therapy [4,

5]. Complex orthodontic movements often require auxiliary components such as resin attachments, notches, anchorage points, precision cuts, bite ramps, or power ridges [6, 7]. To minimize the need for additional refinements when discrepancies occur between planned and achieved tooth positions, or to improve biomechanical efficiency, an elastic resin coating may be applied to the surface of selected teeth (**Figure 1**). For instance, a small elevation on the lingual surface can induce buccal displacement of a tooth.



Figure 1. Clinical photograph showing the “Hill” (marked in red)

The purpose of this resin layer is to reactivate the aligner and adjust its biomechanical function. Its elastic nature allows it to apply a gentle and continuous force, earning it the name “Hill.” The composition and behavior of aligner materials greatly influence the force transmission during treatment and have been the focus of multiple investigations [8]. A wide range of commercial aligner systems exists globally, most relying on transparent thermoformed polymers. The mechanical and clinical performance of aligners are heavily dependent on the intrinsic properties of these materials. Variables such as temperature, water absorption, and repetitive stress can all affect their durability over time.

This study focuses on the mechanical characterization of *Clear-Blok®*, specifically its Young’s modulus, under simulated oral conditions. *Clear-Blok®* is designed as a biomechanical interface applied directly to the tooth surface to improve aligner efficiency through its elastic response. The Young’s modulus, a measure of stiffness and elasticity, serves as an indicator of how the material behaves under stress during orthodontic application. The research explores how factors like polymerization time, environmental exposure, and saliva immersion affect its mechanical integrity. These evaluations aim to provide a clearer understanding of how the material performs in realistic clinical scenarios. The null hypothesis assumes no significant variation in the Young’s modulus between specimens stored in dry conditions and those immersed in artificial saliva.

Materials and Methods

This experimental work was performed at two facilities of the University of Padua, Italy: the UOC Dental Clinic and the Faculty of Materials Engineering, in accordance with ISO 604 guidelines [9]. The investigation was conducted *in vitro* using *Clear-Blok®* (SCHEU-DENTAL GmbH, Iserlohn,

Germany), a light-activated resin (wavelength range: 360–420 nm) formulated for dental use. Its chemical composition includes 40–70% urethane dimethacrylate (UDMA), 20–50% tricyclodecane dimethanol diacrylate (TCDDMDA), and less than 10% 1,4-butanediol dimethacrylate (1,4-BDDMA). The material was chosen due to its transparency, flexibility, ease of molding, light-polymerizing capacity, and ergonomic handling properties. Since neither full mechanical specifications from the manufacturer nor prior published studies existed, this research aimed to determine its Young’s modulus for the first time.

Reusable cylindrical molds, each 6.3 mm in diameter and height, were produced via 3D printing. Stoppers of the same material were fitted into the mold bases to seal one end during resin injection. To ensure easy removal post-curing, both the inner mold walls and stoppers were evenly coated with Vaseline, a neutral substance that does not interfere with light polymerization. The resin was introduced through a syringe equipped with a 0.4 mm cannula, and care was taken to avoid trapping air. Excess resin was removed to maintain a flat surface. Polymerization was then carried out using a VALO™ Corded LED curing light (intensity 1000 mW/cm², wavelength 385–515 nm) for either 5 seconds or 10 seconds.

After curing, samples were ejected by detaching the stopper and gently pressing with a plastic rod. Remaining residues were cleared before reuse. The process was repeated 48 times by the same operator, yielding 24 specimens for each curing time (5 s and 10 s). For every curing group, 12 samples were stored in numbered envelopes at room temperature (NB), and the remaining 12 were placed in test tubes containing artificial saliva at 37°C for 14 days (B) to simulate oral conditions. The saliva’s composition (pH 6.5) is presented in **Table 1** [10]. The 14-day period was chosen since fluid absorption in polymers mainly occurs within 72–168 hours [11–13].

Table 1. Artificial saliva composition used to reproduce human salivary biochemical conditions [9]

Ingredient	Concentration (g/L)
Sodium Chloride	0.6
Potassium Chloride	0.72
Calcium Chloride Dihydrate	0.22
Monopotassium Phosphate	0.68
Disodium Phosphate Dodecahydrate	0.856
Potassium Thiocyanate	0.06
Sodium Bicarbonate	1.5
Citric Acid	0.03

After incubation, all specimens were measured for diameter and height using a digital caliper (± 0.01 mm accuracy). Mechanical behavior was tested through a quasistatic compression test at room temperature with an MTS Acumen 3 electrodynamic system (MTS Systems Corporation, Eden Prairie, MN, USA) and a 3 kN load cell (**Figure 2**). The test parameters included a data collection rate of 5 Hz and a deformation speed of 1 mm/min. Yield strength was defined using the 0.2% offset method, following a linear extrapolation approach. Testing was halted near the machine's mechanical threshold (2400 N, approximately 83 MPa), which did not affect the accuracy of the Young's modulus or yield point determination.

The equipment recorded force (N), displacement (mm), and time (s) for each run. These data, along with the measured sample dimensions, were processed using Microsoft Excel (Office 2021) to compute stress (MPa) and compressive strain (mm/mm). The resulting values were used to construct stress–strain curves for each test (**Figures 3–6**).

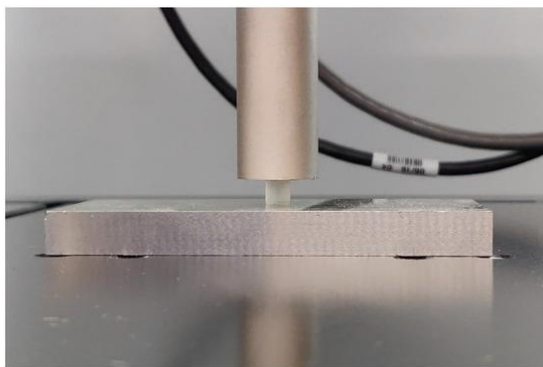


Figure 2. Apparatus setup for compression testing of Clear-Blok® cylindrical samples

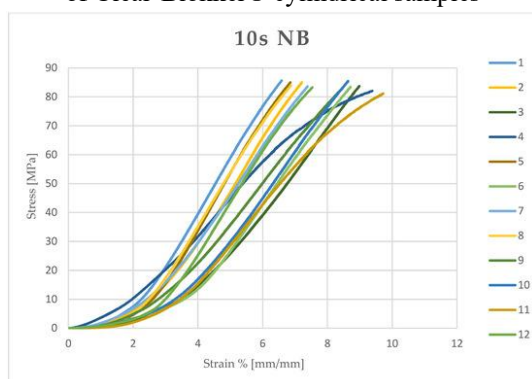


Figure 3. Stress–strain curves for twelve 10-second light-cured samples (10 s) stored in dry conditions (NB)

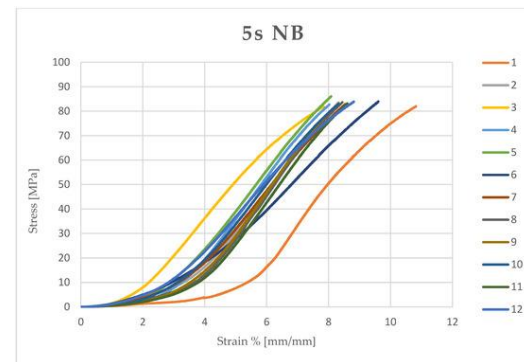


Figure 4. Stress–strain curves for twelve 5-second light-cured samples (5 s) stored in dry conditions (NB)

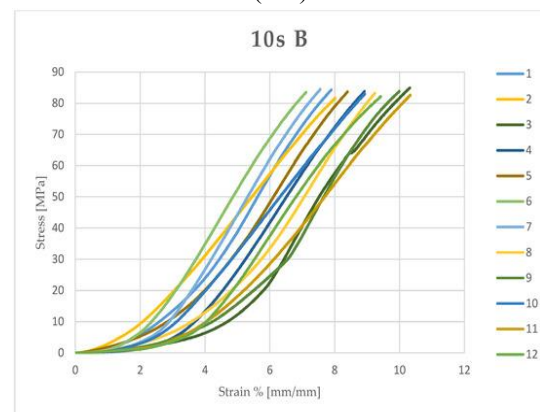


Figure 5. Stress–strain curves for twelve 10-second light-cured samples (10 s) immersed in artificial saliva (B)

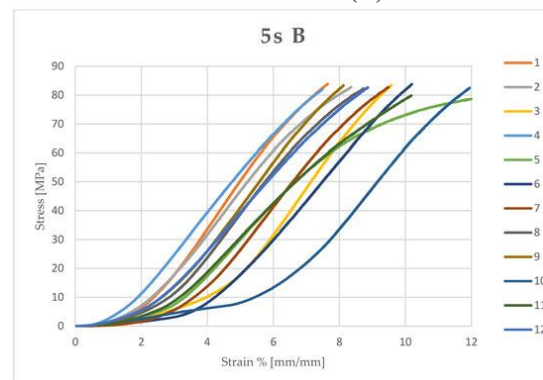


Figure 6. Stress–strain curves for twelve 5-second light-cured samples (5 s) immersed in artificial saliva (B)

We manually identified the portion of each stress–strain curve corresponding to the elastic phase and determined the Young's modulus (MPa) by fitting a linear regression to that region. Additionally, the yield stress (MPa) and strain at yield (mm/mm) were obtained.

A total of 48 cylindrical samples were categorized into four experimental conditions, each consisting of 12 specimens, according to curing duration (5 s or 10 s)

and storage environment (NB or B). The test sets were: 5 s NB, 5 s B, 10 s NB, and 10 s B.

Statistical analysis

The number of samples used was derived from previous studies on dental material mechanics [14, 15], ensuring adequate statistical strength while minimizing inter-sample variability. All data analyses were executed in Statgraphics Centurion 19 (version 19.2.02). The Shapiro–Wilk test verified normal distribution, and Levene’s test confirmed equality of variances. To assess the effect of light-curing duration and exposure condition, a two-way ANOVA (San Francisco, CA, USA) was applied, followed by Tukey’s post hoc comparisons. A p -value < 0.05 indicated statistical significance. Results are expressed as mean $\pm$ standard deviation (SD) with 95% confidence intervals for each condition.

Results

Data from compression testing were processed with Statgraphics Centurion 19 (v. 19.2.02, ©2023 Statgraphics Technologies Inc., The Plains, VA, USA) to compute Young’s modulus. Since the forces required to reach material yield far exceed those encountered during clear aligner therapy, analyses of yield load and yield strain were not included. The dispersion of measurements was visualized through a box plot (Figure 7).

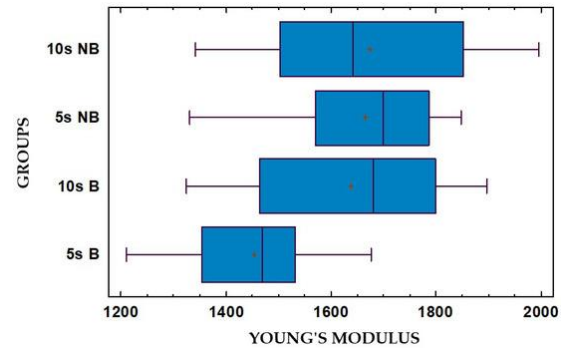


Figure 7. Box plot depicting the Young’s modulus (MPa) of all specimens, divided into four groups based on the factors TIME (10 s or 5 s) and BATH (NB = dry storage, B = immersion). The “+” symbol indicates the group mean

Group statistics, including mean values, standard deviations, and ranges, are reported in **Table 2**. Among the groups, the 5 s B condition exhibited the lowest average modulus. All groups demonstrated minor variability, possibly due to sample preparation inconsistencies (e.g., incomplete polymerization or small trapped air bubbles), though none contained outliers per the Dixon test ($\alpha = 1\%$). After confirming normal data distribution and homogeneous variance using Shapiro–Wilk and Levene’s tests, a multifactor ANOVA was conducted at a 5% significance threshold.

Table 2. Mean, standard deviation, and value range of Young’s modulus (MPa) for the four experimental groups

Category	Average Strength (MPa)	Std. Deviation (MPa)	Lowest Value (MPa)	Highest Value (MPa)	Span (MPa)
10 s Non-Bonded	1673.6	210.1	1340.6	1996.0	655.4
5 s Non-Bonded	1665.9	154.6	1331.4	1847.1	515.7
10 s Bonded	1638.1	203.2	1324.3	1897.1	572.8
5 s Bonded	1454.5	137.7	1210.4	1676.7	466.3

Results revealed that the bath variable had a statistically significant effect ($p = 0.0213^*$), while curing time did not ($p = 0.0710$). No interaction effect between these factors was observed ($p = 0.0960$). The

mean values and 95% confidence intervals for each experimental condition are summarized in **Table 3**, which holds particular importance as determining these means was a principal objective of the investigation.

Table 3. Mean Young’s modulus, standard error, and 95% confidence intervals for each examined factor

Variables	Sample Size	Average Strength (MPa)	Std. Error (MPa)	Lower Boundary (MPa)	Upper Boundary (MPa)
Solution Exposure					
Absent	24	1669.7	36.6	1596.1	1743.4
Present	24	1546.3	36.6	1472.6	1620.0
Duration					
5 Seconds	24	1560.2	36.6	1486.5	1633.9
10 Seconds	24	1655.9	36.6	1582.2	1729.5

Solution × Duration					
Absent—5 s	12	1665.9	51.7	1561.7	1770.1
Absent—10 s	12	1673.6	51.7	1569.4	1777.8
Present—5 s	12	1454.5	51.7	1350.3	1558.7
Present—10 s	12	1638.1	51.7	1533.9	1742.3
Total Average	48	1608.0			

Discussion

This investigation assessed how exposure to artificial saliva and different curing durations, both independently and in combination, influence the Young's modulus of Clear-Blok®. The results demonstrated that storage in artificial saliva caused a noticeable reduction in stiffness, a pattern consistent with the hydrophilic behavior and solubility characteristics typical of dimethacrylate-based polymers. Such findings are clinically important, as they simulate real oral conditions where saliva contact can gradually alter mechanical performance.

The Young's modulus reflects the material's rigidity, quantifying the relationship between applied stress and deformation. A higher value signifies reduced elasticity. Understanding this property is vital for predicting how aligners and auxiliary materials will behave under orthodontic forces. Examining it under simulated oral conditions offers realistic insight into Clear-Blok®'s long-term mechanical reliability.

Compression testing was conducted under quasistatic loading, allowing the material to maintain equilibrium during deformation. This slow testing rate ensures that each stage of the process remains stable, closely approximating actual orthodontic force application, which occurs over extended periods. Therefore, estimating the Young's modulus through this quasistatic method provides an accurate representation of how Clear-Blok® performs in clinical conditions.

Regarding the bath variable, the specimens were submerged in artificial saliva (pH 6.5) maintained at 37 °C, a condition that closely replicates the biochemical environment of the human mouth. This setup enabled the evaluation of possible structural alterations resulting from exposure to moisture, temperature, and acidity. In aqueous surroundings, dimethacrylate-based photopolymer resins tend to absorb water and release unreacted monomers (solubility) that remain after the polymerisation process. For glassy polymers, this process can be represented by a dual-mode sorption model, which includes sites that obey Henry's law of dissolution and others that follow the Langmuir isotherm, referring to absorption within microvoids of the polymer matrix [16, 17].

Polydimethacrylates, as cross-linked glassy polymers, typically exhibit limited permeability to solvents due to their cross-linked molecular architecture. However, a few studies have reported that a higher concentration of cross-links can, under specific conditions, lead to increased water absorption [18]. Previous investigations measured the water uptake and solubility of two major components of Clear-Blok®. One study reported values of 29.46 ± 0.16 $\mu\text{g}/\text{mm}^3$ for water absorption and 6.62 ± 0.12 $\mu\text{g}/\text{mm}^3$ for solubility in UDMA, the resin's principal component. Another found absorption and solubility rates of $1.87 \pm 0.01\%$ and $0.22 \pm 0.03\%$, respectively, for a resin containing UDMA and TCDDMDA [16], both used in the present material. The specific type of methacrylate monomer affects the resin's mechanical and chemical behaviour, and several studies have confirmed that water uptake negatively influences wear resistance, tensile strength, flexural strength, and the elastic modulus of such materials [19–22].

A slightly acidic medium better simulates in vivo oral conditions, though its impact on immersed resin samples develops slowly over time [23]. Temperature, in contrast, has been found to significantly accelerate water absorption and solubility in dental resins [24].

The findings of this experiment demonstrate that both studied factors influence the mechanical characteristics of the tested resin. A statistically significant difference was observed between specimens exposed to simulated oral conditions and those kept dry. The mean Young's modulus for immersed samples was 1546.3 MPa, lower than that of the dry samples (1669.7 MPa) and close to that of PET-G (1870 MPa), a material commonly used in clear aligners stored under similar conditions [25]. The null hypothesis was therefore rejected at a 95% confidence level ($p = 0.0213$).

With respect to the time factor, the ANOVA results showed no significant relationship between the two curing durations and the elastic modulus. Changing the light-curing duration from 5 s to 10 s did not result in statistically significant differences in the Young's modulus between groups. The curing period determines the amount of transmitted light energy, affecting both the polymerisation degree and Knoop microhardness of the resin [26, 27]. Since Young's modulus correlates with microhardness [28], the lack of significance might stem from the minimal difference

between the two curing intervals. For most materials, the major polymerisation reaction occurs within the first 5 seconds, with only minor additional polymerisation afterward [29–31]. Possible experimental errors may have also contributed to data variation. Furthermore, ANOVA did not reject the null hypothesis of no significant interaction between the examined factors at a 5% significance level.

The obtained Young's modulus values correspond well with theoretical expectations. The most clinically meaningful results are those from samples stored in simulated oral conditions. The observed variation in the mechanical performance of Clear-Blok® after immersion parallels the behaviour of other clear-aligner materials [32]. Consequently, Clear-Blok® appears to be a promising candidate for clinical orthodontic applications. We infer that this transparent resin can be effectively applied to tooth surfaces subjected to aligner-induced movement, providing a more elastic interface (1546.7 MPa) than enamel, thereby enhancing the efficiency of orthodontic forces.

Conclusions

The Young's modulus of Clear-Blok®, influenced by light-curing duration and artificial saliva immersion, was slightly below that of PET-G. Immersion in a simulated oral medium significantly affected the resin's mechanical behaviour, as verified through quasistatic compression tests. The average modulus of the immersed samples was lower than that of the dry-stored specimens, closely matching PET-G values and remaining well below the modulus of natural tooth enamel. The variation in curing time (5 s vs. 10 s) showed no significant influence on the results. Given its favourable elastic features, Clear-Blok® may serve as a biomechanical enhancer, improving the force transmission between aligner and tooth surfaces, and potentially offering a viable clinical advantage in more complex orthodontic treatments.

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Conflict of Interest: None

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Ethics Statement: None

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