International Journal Dental and Medical Sciences Research
Volume 6, Issue 4, July. – Aug. 2024 pp 173-178 www.ijdmsrjournal.com ISSN: 2582-6018

Properties Overview of Aligners

Dr.Chitra Agarwal, Dr. Divyaroop Rai, Dr. Shantanu Sharma, Dr. Anurag Tiwari, Dr. Anamika, Dr. Nidhi, Dr. Umang Malviya
[1,7] *Post graduate student,NIMS dental college and hospital, Jaipur, Rajasthan.*
[2]*Professor and HOD,NIMS dental college and hospital, Jaipur, Rajasthan.*
[3,4]*Reader,NIMS dental college and hospital, Jaipur, Rajasthan.*
[5,6]*Senior Lecturer,NIMS dental college and hospital, Jaipur, Rajasthan.*

Date of Submission: 15-07-2024 Date of Acceptance: 25-07-2024

ABSTRACT: Orthodontics and aesthetics have long been complementary fields. The choice of appliance today is driven by the ongoing desire for improved aesthetics as well as the rising number of people seeking orthodontic treatment. Over the past 20 years, clear aligner therapy has become more popular. Clear aligner therapy (CAT) has been endorsed as a cornerstone of orthodontic treatment due to the rapid advancements in biomaterials, computer-aided design (CAD), and manufacturing (CAM). The materials used in the fabrication of aligners have a significant impact on how well they perform clinically. This narrative review has made an effort to fully cover the material attributes that are essential to their success in an oral setting.
KEYWORDS: Clear aligners, Review

I. INTRODUCTION

Malocclusion is defined as the misalignment of teeth or the dental arches of the upper and lower jaw. This disorder is strongly impacted by genetics, but it can also be caused by acquired factors such as poor dental hygiene and early eating habits [1,2]. In response, orthodontics has created a number of biomechanical approaches, including the edgewise appliance, Begg's light wires differential force technique, preadjusted edgewise appliance, and tip edge. Concurrently, there has been a surge of interest in creating less apparent treatment methods, such as lingual orthodontics and thermoplastic aligner systems [3].

Clear aligners, which are becoming increasingly popular in orthodontic treatment, are viewed as an appealing, removable alternative to standard fixed-appliance treatments for mild to moderate cases, providing patients with comfort and aesthetic benefits while minimizing clinician chair time [4,5]. These aligners are often constructed from thermoplastic polymer materials such as polyurethane or polyethylene terephthalate glycol, which are known for their biocompatibility, flexibility, elasticity, and resilience to chemical and mechanical wear [6-8].

However, clear aligners' biomechanical qualities can deteriorate after being worn in the mouth, resulting in a loss of transparency and mechanical strength, as well as changes in hardness, abrasion resistance, distortion, and the formation of cracks [9-11]. Previous research has looked at these alterations, but not the continual changes in biomechanical properties that occur throughout the treatment period [8,9,11]. A report comparing orthodontic discomfort in patients using clear aligners to fixed appliances found that aligners applied less force, while this finding is still contentious in clinical settings [12]. The ongoing study attempts to evaluate these attributes more completely, including flexural strength, translucency, roughness, hardness, and tensile strength.

With considerable breakthroughs in biomaterials and computer-aided design and manufacturing (CAD/CAM) technologies, clear aligner treatment (CAT) has emerged as a viable alternative to traditional fixed appliances (FAs) in orthodontics. CAT involves the use of a set of transparent plastic trays that securely cover the patient's teeth and are supposed to be worn constantly except while eating and cleaning. These aligners are usually changed every one to two weeks to gradually accomplish the required orthodontic tooth motions. Today, there are various commercial clear aligner systems available worldwide, but they all use clear thermoformed plastic materials to fabricate the aligners [13].

A number of factors influence the clinical effectiveness of clear aligners [14,15,16,17,18], but the qualities of the materials used in their manufacture are critical in determining their mechanical and clinical performance [19]. This review investigates the qualities of several materials used in the production of clear aligners, highlighting their impact on the therapy's overall efficacy.

II. PROPERTIES OF CLEAR ALIGNER MATERIALS

Thermoplastic materials utilized in the fabrication of clear orthodontic aligners are generally polymers with varying properties that respond differently to the various forms of stress encountered in the mouth environment. These stresses include mechanical stress from functional and parafunctional movements, thermal stress from the aligner thermoforming process and variations in mouth temperature, and chemical stress from saliva exposure and beverage consumption [20,21].Asuitable material for aligners should have several characteristics, including high resilience, low hardness, acceptable elasticity, and resistance to stress and distortion. It should also maintain great transparency, have low cytotoxicity, and be highly biocompatible [20]. Changes in these qualities have a substantial impact on the clinical success of clear aligners in orthodontic treatments.

A. Mechanical properties, stress relaxation phenomenon and the physical performance of clear aligner materials

An appropriate aligner material must be stiff enough to apply the pressures and moments required for the desired tooth movement. If the material used to make an aligner has a high modulus of elasticity, or is highly stiff, the resulting aligner will be quite rigid, making it difficult for patients to insert and remove. In contrast, a material with insufficient stiffness may fail to create the requisite forces to efficiently move teeth [22].

Aligners are known to absorb less energy because they deform permanently at moderate-to-heavy pressures [23], and they have much lower resilience than metal archwires [24]. For example, tooth crowding that may be treated with a single nickel-titanium archwire may necessitate the use of several aligners to get the same result. Metal archwires are excellent at storing and delivering energy to the teeth over time, with minimum strain.

Known as "viscoelastic," clear aligner materials have characteristics that lie halfway between those of entirely elastic and purely viscous materials. When introduced to a load, as when an aligner is initially applied to the dentition—even before to any intended tooth movement—the behaviour of viscoelastic materials can undergo significant changes over time [25]. Relatively little energy is delivered to the teeth by aligners; the majority of the energy they do absorb is lost as heat. The viscoelastic materials' innate capacity to absorb shock, vibrations, and force enables the aligner to stretch and deform, producing the necessary forces for the tooth movement once the aligner is attached to the teeth [26].

When aligners are put onto teeth, stress relaxation in them lessens the pressures they apply, resulting in a consistent rate of deflection before tooth movement starts. The aligners' material properties and the strength of the applied force both affect this relaxation. With transparent aligners, force decreases exponentially rather than linearly over time, with a notable decrease in force occurring during the first few hours of use, which is suggestive of material fatigue [26].

Two single-layer materials based on PETG and polyurethane, two multi-layer materials, and two single-layer materials were the subjects of a study by Lombardo and colleagues [26] on the mechanical properties and stress relaxation of aligner materials. According to their research, multi-layer materials had consistent stress relaxation and absolute stress resistance that was four times lower than that of single-layer materials, whereas single-layer materials shown significant resistance to absolute stress and quick stress relaxation. Furthermore, within the first eight hours, all four materials showed a large quick stress relaxation; after that, some materials reached a plateau, while the other materials showed a drop. The single-layer PETG material showed the greatest stress relaxation rate over a 24-hour period, while the polyurethane-based single-layer material exhibited greater beginning stress values and a high decay rate. When compared to single-layer materials, multi-layered materials generally showed lower stress relaxation rates and starting stress values.

In conclusion, aligners usually have low forces, have little flexibility, perform better with fewer activations, and experience quick force decay [27]. Because the aligner material is viscoelastic, the force it produces for a given deformation decreases depending on a number of factors, including the thickness of the material used in its fabrication, the temperature of the oral cavity, the composition of the thermoplastic material, and the amount of force applied to a particular area of the aligner [21].

B. Thermal properties and the influence of the thermoforming process on clear aligner behaviour

One of the most important aspects of the functionality of aligner materials is their ability to successfully conform to dental models during the thermoforming process. It has been demonstrated that polyurethane materials are more adaptable than other options at a particular temperature of about

110 °C [28,29]. Studies have repeatedly shown that during the thermoforming process—which is utilized to create clear aligners—aligner materials' hardness, thickness, and transparency change significantly [30,31].

A thorough investigation comparing the thickness and transparency of aligner materials prior to, and following thermoforming was carried out by Ryu et al. [31]. Four distinct types of clear aligner materials were investigated in this study; two of them were based on copolyesters (Essix A+ and Essix ACE), and the other two were based on PETG (Duran and ECligner). The results showed that all materials had an overall decrease in transparency after thermoforming. Significantly less transparent than Duran and Essix A+ samples of same thickness, the eCligner samples with thicknesses of 0.5 mm and 0.75 mm showed a considerable reduction in transparency. Comparing the 0.75 mm thick Essix ACE samples to the eCligner material of the same thickness, there was also a noticeable drop in transparency.

Furthermore, after thermoforming, the Duran and Essix A+ samples likewise shown a notable decrease in transparency. In contrast to the eCligner sample, the Duran, Essix A+, and Essix ACE samples all exhibited a notable increase in solubility in water, while the hardness of all four materials showed no discernible changes from their pre-thermoforming forms. In addition, the thermoforming procedure resulted in a greater surface hardness for the Essix A+ and Essix ACE samples than before.

Dalaie and colleagues conducted an additional in vitro investigation [32] to investigate the changes in the thermomechanical properties of two PETG aligner sheets that underwent thermoforming. The sheets' thicknesses were 1 mm and 0.8 mm. This study demonstrated how the thermoforming process affects material attributes by finding that the hardness of the material dropped by about 7.6% for both thicknesses after thermoforming.

C. Optical properties, colour stability and clear aligner transparency

Excellent light transmittance is anticipated from aligner materials; for maximum clarity, at least 80% of visible light should be transmitted. For clear aligner materials, amorphous thermoplastic polymers—which are highly translucent—are favoured over crystalline polymers, which are typically opaque and less visually beautiful. Due to their favourable optical characteristics, polymers including as polyester, polyvinyl chloride, polysulfone, polycarbonate, and polyurethane are especially preferred for the manufacturing of commercial aligners [33].

The color stability and transparency of clear aligners when exposed to different coloring agents and saliva have been thoroughly studied [32,34]. Research has evaluated a variety of materials used in clear aligners, such as resin-based polyurethane material (Zendura), co-polyester material (Essix ACE), co-layered thermoplastic polyurethane with integrated elastomer (SmartTrackTM), PETG material (Erkodur), and two PET-based materials (Essix Plastic and Ghost aligner). Visual examinations of color stability showed that, in general, after being exposed to popular coloring agents such as wine, coffee, black tea, cola, and nicotine for 12 hours, no material showed any change in color. Red wine and coffee, however, caused dramatic color changes in the SmartTrackTM material, which was an exception [32,34].

This emphasizes how important it is to choose materials carefully when constructing aligners in order to guarantee both functional endurance and cosmetic appeal under normal usage circumstances.

D. Chemical resistance properties, the influence of the oral environment and clear aligner aging

The dynamic conditions of the oral cavity, including as temperature changes, exposure to saliva and its different enzymes, and infrequent contact with liquids other than water, are frequently experienced by clear aligners. These elements may have a negative impact on the thermoplastic polymers' chemical makeup, which could eventually change the aligners' mechanical or form properties. In particular, the polymer structure of some polyesters, such as polycarbonates and polyamides, may degrade due to irreversible hydrolysis. For this reason, it is essential that the polymers chosen for the production of clear aligners demonstrate resistance to hydrolysis and water degradation [22].

After a hot beverage is consumed, the temperature in the oral cavity can rise to 57 °C. It takes several minutes for the temperature to return to normal. Numerous in vivo and in vitro investigations have shown that these temperature variations have an effect on the mechanical properties of thermoplastic materials [30,32,35]. Invisalign aligners used for a two-week period have also been linked to problems such microcracks, delaminated areas, calcified biofilm deposits, and loss of aligner transparency [36,37].Intraoral hygroscopic expansion can also lead to changes in the aligner's fit and the orthodontic forces it applies. Research has indicated that thermoplastic materials exhibit increasing water absorption over time, with the material used in Invisalign aligners exhibiting the highest absorption rate followed by PETG [35].

Eight common thermoplastic materials were examined in an in vitro study [35] from various commercial manufacturers. The materials included PETG (Duran), PC (polycarbonate, Imprelon"S"), PP (polypropylene, Hardcast), PUR (polyurethane, Invisalign), A+ (Copolyester, Essix A+), C+ (polypropylene/ethylene copolymer, Essix C+), PE (polyethylene, Copyplast), and EVA (ethylene-vinyl acetate copolymer, Bioplast). To test these materials' response to oral circumstances, they were submerged in a solution that mimicked an oral environment. The study discovered that after being exposed to the intraoral environment, the elastic moduli of PC, Essix A+, and PETG increased significantly in comparison to their initial states. On the other hand, the elastic moduli of PP, Essix C+, PE, and EVA significantly decreased. There were no discernible alterations found in the PUR substance. The study also observed that water absorption caused an increase in the overall thickness of all tested thermoplastic materials.

In 2019, Bucci et al. conducted an in vivo study [30] to assess the impact of temperature fluctuations in the oral cavity, together with normal and parafunctional oral functioning, on clear aligners. During the course of 10 days, patients were instructed to wear passive and active aligners made from PETG sheets for 22 hours each day. After ten days, the study found that the aligners' thickness had somewhat decreased, but it also found that these changes were insignificant enough to have no effect on the transparent aligners' clinical efficacy, indicating that PETG offers enough stability in the oral environment.

E. Biocompatibility and cytotoxicity of clear aligners materials

The FDA conducted a retrospective review, and Allareddy and colleagues produced a thorough overview of the adverse clinical events connected to the use of Invisalign aligners. During a ten-year study period, breathing difficulties, sore throats, enlarged throats, swollen tongues, hives, itching, and anaphylactic reactions were the most often reported side effects linked to these aligners [38].

A study on the cytotoxic effects of four distinct aligner materials—Duran (Germany), Biolon (Germany), Zendura (United States), and SmartTrackTM (United States)—was also carried out by Ahrari and co-authors [39]. According to their research, Biolon, Zendura, and SmartTrackTM caused the greatest harmful effects on human gingival fibroblasts (HGFs). Conversely, Duran exhibited the least amount of cytotoxicity of all the materials examined. Because material choice might affect patient safety and health, this study emphasizes how important it is when making aligners.

III. CONCLUSION

The material used to fabricate the aligners has a significant impact on the clinical performance of transparent aligners, which is why clear aligner therapy is now a widely acknowledged orthodontic treatment staple.

The narrative review aims to provide a thorough understanding of the range of materials currently utilized in the production of clear aligners, with a focus on their mechanical, chemical, optical, thermal, and biological properties. These attributes are critical in determining the clear aligners' clinical performance in an oral environment.

REFERENCES

[1]. Principles and Biomechanics of Aligner Treatment, 1st ed.; Elsevier: Amsterdam, The Netherlands, 2021.
[2]. Profitt, W. Contemporary Orthodontics, 6th ed.; Elsevier: Amsterdam, The Netherlands, 2020.
[3]. Tuncay OC. The Invisalign System. Quintessence; 2006
[4]. Angle E. The latest and best in orthodontic mechanism (2). Dental Cosmos. 1929;71:164–174.
[5]. Zheng M, Liu R, Ni Z, Yu Z. Efficiency, effectiveness and treatment stability of clear aligners: a systematic review and meta analysis. OrthodCraniofac Res. 2017;20:127–33.
[6]. Daniele V, Macera L, Taglieri G, Di Giambattista A, Spagnoli G, Massaria A, et al. Thermoplastic disks used for commercial orthodontic aligners: complete physicochemical and mechanical characterization. Materials (Basel). 2020;13:2386.
[7]. Qi HJ, Boyce MC. Stress-strain behavior of thermoplastic polyurethanes. Mech Mater. 2005;37:817–39.
[8]. Condo R, Pazzini L, Cerroni L, Pasquantonio G, Lagana G, Pecora A, et al. Mechanical properties of “two

generations" of teeth aligners: change analysis during oral permanence. Dent Mater J. 2018;37:835–42.

[9]. Gerard Bradley T, Teske L, Eliades G, Zinelis S, Eliades T. Do the mechanical and chemical properties of Invisalign TM appliances change after use? A retrieval analysis. Eur J Orthod. 2015;38: 27–31.

[10]. Schuster S, Eliades G, Zinelis S, Eliades T, Bradley TG. Structural conformation and leaching from in vitro aged and retrieved Invisalign appliances. Am J Orthod Dentofacial Orthop. 2004;126:725–8.

[11]. Gracco A, Mazzoli A, Favoni O, Conti C, Ferraris P, Tosi G, et al. Short-term chemical and physical changes in invisalign appliances. Aust Orthod J. 2009;25:34–40.

[12]. Almasoun, N.N. Pain perception among patients treated with passive self-ligating fixed appliances and Invisalign® aligners during the first week of orthodontic treatment. Korean J. Orthod. 2018, 48, 326–332.

[13]. Hartshorne J., Wertheimer M.B. Emerging insights and new developments in clear aligner therapy: a review of the literature. Am. J. Orthod. Dentofacial Orthop. Clin. Companion. 2022;2(4):311–324.

[14]. Rossini G., Parrini S., Castroflorio T., Deregibus A., Debernardi C.L. Efficacy of clear aligners in controlling orthodontic tooth movement. A systematic review. Angle Orthod. 2015;85(5):881–889.

[15]. Kravitz N.D., Kusnoto B., BeGole E., Obrez A., Agran B. How well does Invisalign work? A prospective clinical study evaluating the efficacy of tooth movement with Invisalign. Am. J. Orthod. Dentofacial Orthop. 2009;135(1):27–35.

[16]. Haouili N., Kravitz N.D., Vaid N.R., Ferguson D.J., Makki L. Has Invisalign improved? A prospective follow-up study on the efficacy of tooth movement with Invisalign. Am. J. Orthod. Dentofacial Orthop. 2020;158(3):420–425.

[17]. Al-Nadawi M., Kravitz N.D., Hansa I., Makki L., Ferguson D.j., Vaid N.R. Effect of clear aligner wear protocol on the efficacy of tooth movement: a randomized clinical trial. Angle Orthod. 2021;91(2):157–163.

[18]. Karras T., Singh M., Karkazis E., Liu D., Nimeri G., Ahuja B. Efficacy of Invisalign attachments: a retrospective study. Am. J. Orthod. Dentofacial Orthop. 2021;160(2):250–258

[19]. Tamburrino F., D'Anto V., Bucci R., Alessandri-Bonetti G., Barone S., Razionale A.V. Mechanical properties of thermoplastic polymers for aligner manufacturing: in vitro study. Dent. J. 2020;8(2):47.

[20]. Ma Y.S., Fang D.Y., Zhang N., Ding X.J., Zhang K.Y., Bai Y.X. Mechanical properties of orthodontic thermoplastics PETG/PC2858 after blending. Chin. J. Dent. Res. 2016;19(1):43–48.

[21]. Lombardo L., Arreghini A., Maccarrone R., Bianchi A., Scalia S., Siciliani G. Optical properties of orthodontic aligners--spectrophotometry analysis of three types before and after aging. Prog. Orthod. 2015;16(1):41.

[22]. Gold B.P., Siva S., Duraisamy S., Idaayath A., Kannan R. Properties of orthodontic clear aligner materials - a review. J. Evolution Med. Dent. Sci. 2021;10(37):3288–3294.

[23]. Abdallah M.N., et al. Advanced Dental Biomaterials. Elsevier; Philadelphia: 2019. Biomaterials used in orthodontics: brackets, archwires, and clear aligners; pp. 541–579.

[24]. Kwon J.S., Lee Y.K., Lim B.S., Lim Y.K. Force delivery properties of thermoplastic orthodontic materials. Am. J. Orthod. Dentofacial Orthop. 2008;133(2):228–234.

[25]. Macri M., Murmura G., Varvara G., Traini T., Festa F. Clinical performances and biological features of clear aligners materials in orthodontics. Front. Mater. 2022;9

[26]. Lombardo L., Marines E., Mazzanti V., Arreghini A., Molica F., Siciliani G. Stress relaxation properties of four orthodontic aligner materials: a 24-hour in vitro study. Angle Orthod. 2017;87(1):11–18.

[27]. Jindal P., Juneja M., Siena F.L., Bajaj D., Breedon P. Mechanical and geometric properties of thermoformed and 3D printed clear aligners. Am. J. Orthod. Dentofacial Orthop. 2019;156(5):694–701.

[28]. Zafeiriadis A.A., Karamouzos A., Athanasiou A.E., Eliades T., Palaghias G. An in vivo spectrophotometric evaluation

of Vivera and Essix clear thermoplastic retainer discoloration. Aust. Orthod. J. 2018;34(1):3–10.

[29]. Talic N.F., Almudhi A.A. The effect of dietary pigmentation on the esthetic appearance of clear orthodontic elastomeric modules. J. Orthod. Sci. 2016;5(2):70–73.

[30]. Bucci R., Rongo R., Levatè C., Michelotti A., Barone S., Razionale A.V., et al. Thickness of orthodontic clear aligners after thermoforming and after 10 days of intraoral exposure: a prospective clinical study. Prog. Orthod. 2019;20(1):36.

[31]. Ryu J.H., Kwon J.S., Jiang H.B., Cha J.Y., Kim K.M. Effects of thermoforming on the physical and mechanical properties of thermoplastic materials for transparent orthodontic aligners. Korean J. Orthod. 2018;48(5):316–325.

[32]. Dalaie K., Fatemi S.M., Ghaffari S. Dynamic mechanical and thermal properties of clear aligners after thermoforming and aging. Prog. Orthod. 2021;22(1):15.

[33]. Liu C.L., Sun W.T., Liao W., Lu W.X., Li Q.W., Jeong Y., et al. Color stabilities of three types of orthodontic clear aligners exposed to staining agents. Int. J. Oral Sci. 2016;8(4):246–253.

[34]. Liu C.L., Sun W.T., Liao W., Lu W.X., Li Q.W., Jeong Y., et al. Colour stabilities of three types of orthodontic clear aligners exposed to staining agents. Int. J. Oral Sci. 2016;8(4):246–253.

[35]. Ryokawa H., Miyazaki Y., Fujishima A., Miyazaki T., Maki K. The mechanical properties of dental thermoplastic materials in a simulated intraoral environment. Orthod. Waves. 2006;65(2):64–72.

[36]. Schuster S., Eliades G., Zinelis S., Eliades T., Bradley T.G. Structural conformation and leaching from in vitro aged and retrieved Invisalign appliances. Am. J. Orthod. Dentofacial Orthop. 2004;126(6):725–728.

[37]. Gracco A., Mazzoli A., Favoni O., Conti C., Ferraris P., Tosi G., et al. Short-term chemical and physical changes in Invisalign appliances. Aust. Orthod. J. 2009;25(1):34–40.

[38]. Allareddy V., Nalliah R., Lee M.K., Rampa S., Allareddy V. Adverse clinical events reported during Invisalign treatment: analysis of the MAUDE database. Am. J. Orthod. Dentofacial Orthop. 2017;152(5):706–710.

[39]. Ahrari F., Afshari J.T., Poosti M., Brook A. A. Cytotoxicity of orthodontic bonding adhesive resins on human oral fibroblasts. Eur. J. Orthod. 2010;32(6):688–692.