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SYSTEM SAFETY: HUMAN - TECHNICAL FACILITY – ENVIRONMENT
7(1), 2025, pp. 406-418

EXPLORING THE IMPACT OF PRIMER ADHESIVES FLOW PROPERTIES ON ORTHODONTIC BONDING

DOI: 10.2478/czoto-2025-0038
Received: 20/11/2025
Accepted: 09/12/2025

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Abstract: The aim of this study was to investigate the viscosity and flow behavior of three orthodontic bonding agents (3M, B&E and Morley) in relation to their time-dependent shear bond strength (SBS) in the clinical application. All adhesives exhibited a non-Newtonian, shear-thinning rheology where solvent viscosity reduction occurs and increases in response to shear rate. The attributes of the flows were found to follow the power law model which was applied on the study sites. Chemical structure and functional groups in each adhesive were identified using Fourier-transform infrared spectroscopy (FTIR) analysis. For Morley composite resin, adhesives exhibited the following decreasing viscosity (at low shear rate) order: highest 3M, B&E, then Morley. Nonetheless, at a greater shear rate (60 s^{-1}), viscosity trends were reversed, as 3M and B&E maintained their shear-thinning properties, and Morley sintered showing fully shear-thickening behavior. In addition, SBS values were inversely correlated to viscosity, with lower viscosity adhesives exhibiting higher bond strength. The viscosity measurements, as well as the corresponding SBS results, showed good correlations with flow index (n) and viscosity constant (k). These results delineate the importance of rheology in designing the properties of orthodontic adhesives, which may be pivotal for obtaining the desired outcome in terms of bonding and clinical performance, and ultimately viscosities similar to that of the adhesive used in this study should be targeted.
Keywords: shear bond strength, rheology, non-newtonian fluids, orthodontic adhesives, flow curve modeling.

1. INTRODUCTION

This is because the bond between the orthodontic brackets and the enamel must be strong enough to obtain the therapeutic objectives of orthodontic treatment (Kiryk et al. 2025). The braces must be removed after the treatment period is over. Therefore, the retainers must be able to withstand the forces applied to the orthodontic braces during the treatment period without causing damage to the tooth after the separation process (Condò et al. 2021; Yan et al., 2025). The assessment of adhesion strength serves as a standard

procedure to evaluate the performance and reliability of dental adhesive materials (Kux et al., 2022). The shear bond strength depends on various factors such as the drill material, bracket type; adhesive, photo curing units and restoration materials have been reported (Zaki et al., 2023; Sayed, 2025). variety of orthodontic adhesives are currently utilized for securing brackets, bands, and other appliances. Composite adhesives are widely preferred due to their superior mechanical performance, reduced failure rates, and favorable aesthetic outcomes (Barkmeier and Cooley,1992). Among these, flowable or low-viscosity composites have gained attention for orthodontic purposes. In these composites, some fine-size particle hybrid concept is retained as in such hybrid-landed composites while with reduced filler concentration, so lowing viscosity (Bilen and Çokakoğlu, 2020). Research indicates that dental resin composites can release certain components – such as diluents (e.g., triethylene glycol Dimethacrylate or TEGDMA), plasticizers (e.g., dicyclohexyl phthalate and bis(2-ethylhexyl) phthalate), and other additives – which may compromise the stability of collagen and proteins in the oral environment by enhancing enzymatic degradation. Additionally, TEGDMA has been associated with mutagenic potential in vitro studies (Carreau, 1972; Cross, 1965). For this reason, things that are easily dissolved or broken down chemically might not be good for therapy. This is the reason why it is necessary to conduct an assessment of the possible mechanical and characteristics of new adhesive materials in order to ensure that they are biocompatible and behave in a secure manner within the oral cavity. There are variations in viscosity and filler particle content among the orthodontic resins that are available for commercial use (Par et al., 2025). Because of its flow characteristics and its capacity to efficiently permeate enamel rods, the polymer component is an essential part of the bonding process. For the purpose of adhering brackets to the enamel surface, it engages in a synergistic relationship with orthodontic adhesives (Wiertelak-Makała et al., 2023; Hussein and Yassir, 2024). Additionally, low-viscosity primers are able to facilitate better adaptation to the enamel surface, which is an important role that the adhesive primer plays in the process of optimising the interface between the enamel and the composite resin. Mechanical interlocking, which is essential to bond strength, is improved as a result of this (Kim et al., 2025). Using a primer with a lower viscosity allows for more uniform spreading, which in turn increases the contact area and enables more precise bracket replacement (Brantley and Eliades, 2001). Modifications to the monomeric and filler compositions of adhesive resins and primers have resulted in significant advancements in the development of superior adhesive resins and primers. At the interface between the bracket and the tooth, the bonding effectiveness is directly influenced by the viscosity of the adhesive (Sharifi et al., 2022). There is better followability is linked to deeper penetration into enamel microstructures and stronger adhesion in general. this link was found to exist. When compared to their counterparts with a higher viscosity, cements with a low viscosity display a greater capacity to penetrate the pores of enamel (Aboujaoude et al., 2022). Numerous researchers have used nanoparticles in an effort to enhance adhesion qualities, which has been made possible by the development of nanotechnology (Nikpour et al., 2021). Nanotechnology plays a vital role in the prevention of dental caries via two mechanisms. The first is to put in substances with properties that kill germs, such as nanoparticles of zinc oxide (ZnO) and titanium dioxide (TiO2). The second type of materials are calcium fluoride (CaF_2) and Ca hydroxyapatite ($Ca_{10}(PO_4)_6(OH)_2$), which provide F^- and Ca^{2+} ions, respectively (Ahmadian et al., 2018). Hydroxyapatite particles have a long history of use in the medical and dental professions (Hasan, 2021). Calcium

hydroxyapatite NPs can create micropores in the enamel of teeth by releasing inorganic ions (Priyadarsini et al., 2018). Tthe ions will seep between the leaflets and at remineralization they are converted into hydroxyapatite crystals (Fierascu, 2022). In addition, those nanoparticles have good antibacterial activity for the quick degrading process and ion release and reactive oxygen species generation (Seyedmajidi et al., 2018; Hwang et al., 2022). The purpose of this work is to study the relationship between SBS and rheological characteristics (including shear viscosity, shear stress and flow type) of orthodontic adhesives. Three commercial adhesives, 3M, B&E and Morley were compared by a cone-plate viscometer. The major aim is to investigate whether predicting shear bond strength using rheology parameters can be used as a low-cost, time-saving and chairside test for the most suitable adhesive in clinical orthodontics.

2. MATERIALS AND METHODS

2.1. Materials Used

Table 1
Materials that used in this study.

Product Name	Properties	Country of manufacture
Transbond™ XT Primer	Unfilled primer, provides high bond strength, used with Transbond Adhesive	United States
B&E Light Cure Orthodontic Primer	Provides good bonding strength, easy to use, compatible with most reinforcing adhesives	South Korea
Morley Orthodontic Primer	It features convenient working time and good bonding strength,	China

2.2. Specimens Preparation

A 2% modified micro-hydroxyapatite addition to dental adhesive was prepared according to the following formula (Adnan and Agha, 2024).

$$\text{Weight of micro-particles} = \text{Weight of adhesive} \times 2\% \quad (1)$$

The micro-hydroxyapatite particles were accurately weighed on an analytical balance and mixed with adhesive in a lightproof room. The mixing was performed with a plastic spatula on a glass slab to obtain a uniform color and smooth consistency. The modified adhesive resin thus obtained was placed in a sterile disposable syringe and covered with black tape to shield it from light (Hadi et al., 2025). The current ex vivo study was conducted on 36 non-carious human premolar teeth extracted for orthodontic purpose. The extracted teeth showed no evidence suggestions of caries, fluorosis, structural defects, fractures, chemical bleaching previous history or surface wear. All specimens were cleaned until residual soft tissue and any detritus was removed. The extracted teeth were kept in 0.1% thymol solution at room temperature to simulate clinical conditions and to maintain aseptic and dry sample storage. They were housed in sealed containers to prevent leakage during storage or transport. Before bonding, the tooth surfaces were conditioned with 37% phosphoric acid for 30 seconds to create surface roughness, followed by a 20-second rinse with distilled water and air-drying until a chalky white appearance was

observed. Three adhesive systems (3M, B & E and Morley) were also bonded to enamel surfaces for 5 sec., air blasted for another 5 sec., and light cured for 30 seconds. The 2% $Ca_5(PO_4)_3(OH)$(HA)/Morley resin composite was used to orthodontic brackets bonding on the enamel surface. Both sides of the bracket were then light-cured for 60 seconds to ensure total polymerization.

2.3. Characterization

2.3.1. Cone-plate Viscometer

The flow behavior was evaluated using a "BROOKFIELD" cone-plate viscometer at a temperature of 25 degrees Celsius, two milliliters of each primer were withdrawn using a syringe and placed in the device for testing.as shown in Figure 1a, b. This instrument provides a uniform shear rate and enables direct measurement of initial normal stress. Widely regarded as a standard tool for characterizing non-Newtonian fluids, the cone-plate viscometer allows for straightforward calculation of shear stress and shear rate. Using this device, both viscosity and flow curves of the adhesives were generated across a range of shear rates.

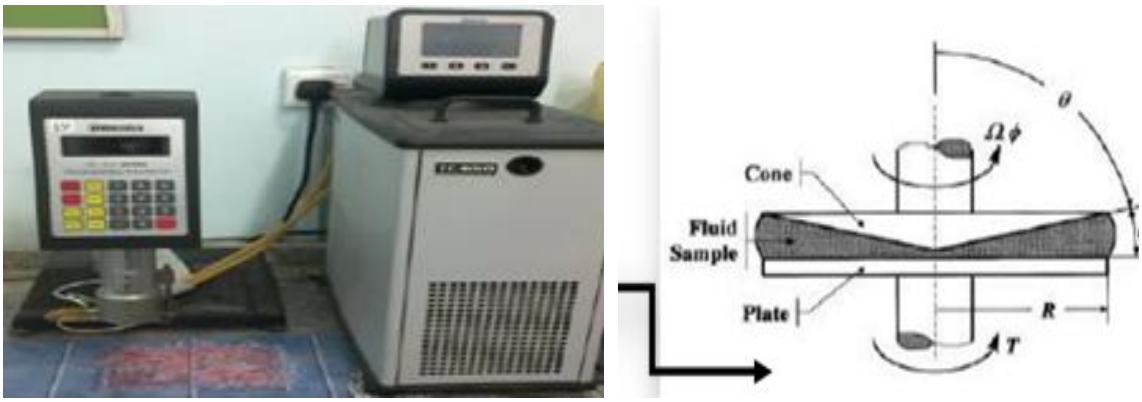
$$\tau = \frac{3T}{2\pi R^3} \quad (2)$$

$$\dot{\gamma} = \frac{\Omega}{\tan\alpha} \quad (3)$$

Where: R is the radius of the cone (m), T is the applied torque (N·m), Ω is the angular velocity (rad/s), α is the cone angle (rad), and $\dot{\gamma}$ is the shear rate (s^{-1}).

$$\mu = \frac{3T\alpha}{2\pi R^3\,\Omega} \quad (4)$$

Where μ is the shear viscosity.



a B

Fig. 1. (a) Cone-and-plate viscometer setup. (b) Schematic of cone-and-plate geometry.

2.3.2. Mathematical Models

Rheology lite for window, an app. for rheology analysis of the flow behavior of materials was used to understand how the shear rate affects the viscosity of a non-Newtonian material. This Rheology Lite for Windows software is created, programmed and published by Sumanta Raha. Common viscosity models include the Cross model, Carreau model, Carreau-Yasuda model, and the power law model were applied to the flow curves of the three bonds. The following rheological properties of the material can be obtained (Frankenberger et al., 2002).

2.3.2.1. Zero Shear Viscosity

The limiting value of the viscosity of a material effectively at rest. This important parameter helps us understand the storage stability of suspensions, the molecular weight of polymeric materials, and the deformation behavior of materials under low stresses such as brushing.

2.3.2.2. Shear Thinning Index n

A measure of non-Newtonian materials - how much its viscosity changes from low shear conditions to high shear conditions. A value less than one means a shear thinning material (i.e., the viscosity reduces as the shear rate increases), a value more than one means a shear thickening material (i.e., the viscosity increases as the shear rate increases), and a value equal one means a Newtonian material (i.e., the viscosity is constant irrespective of the shear rate).

2.3.2.3. Infinite Shear Viscosity

For some shear thinning materials, the initial decrease in viscosity reaches a final constant value at very high shear rates.

2.3.3. Fourier Transform Infrared Spectroscopy FTIR

Fourier Transform Infrared (FTIR) spectroscopy of the adhesive samples was conducted using the KBr pellet technique with a Type IR Affinity-1 spectrometer (Kyoto, Japan). Each adhesive – 3M, B&E, and Morley – was mixed with potassium bromide (KBr) in a 1:10 mass ratio. The mixtures were finely ground, pressed into pellets, and mounted onto the FTIR sample holder. The system aligned the reconstructed infrared beam with the specimen and directed it toward the detector. FTIR spectroscopy operates by analyzing the absorption, emission, or scattering of infrared radiation, enabling the identification and quantification of functional groups in bimolecular structures. It is widely employed in the characterization of biomaterials. Spectral data were recorded within the mid-infrared range of 500 to 4000 cm^{-1}.

2.3.4. Shear Bond Strength (SBS)

Shear bond strength (SBS) is defined as the amount of force required to deboned an orthodontic bracket from the tooth surface, normalized by the bracket's base area. In this study, SBS was assessed 24 hours after bracket placement at the University of Babylon, College of Materials Engineering, Department of Polymer and Petrochemical Industries. A universal testing machine as shown in the Figure 2 was employed, utilizing a chisel-shaped blade positioned at the adhesive–tooth interface in an occlusion-gingival direction. Force was applied at a crosshead speed of 0.5 mm/min until bond failure occurred. SBS was calculated using the following formula: SBS (MPa) = Applied force (N) / Bracket base area (mm^2) (Knox et al., 2000).

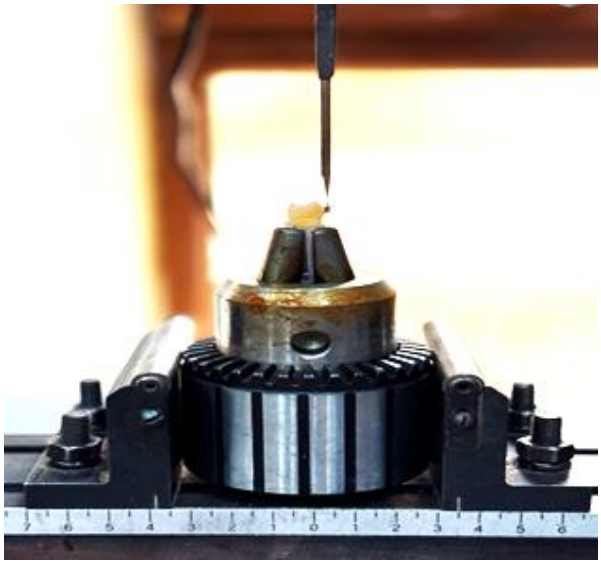


Fig. 2. Shear bond strength test mechanism.

3. RESULTS AND DECISION

3.1. Rheology (Viscosity Curve and Flow Curve)

Viscosity curve shows the relationship between shear viscosity and shear rate, while flow curve presents the relationship of shear stress and shear rate. Figure 3 displays the shear viscosity profiles of the 3M, B&E, and Morley adhesive bonds over a shear rate range of 0 to 100 s^{-1} at 25°C. All three bonds exhibited non-Newtonian flow behavior. The 3M and B&E bonds demonstrated shear-thinning characteristics, while the Morley bond showed shear-thickening behavior.

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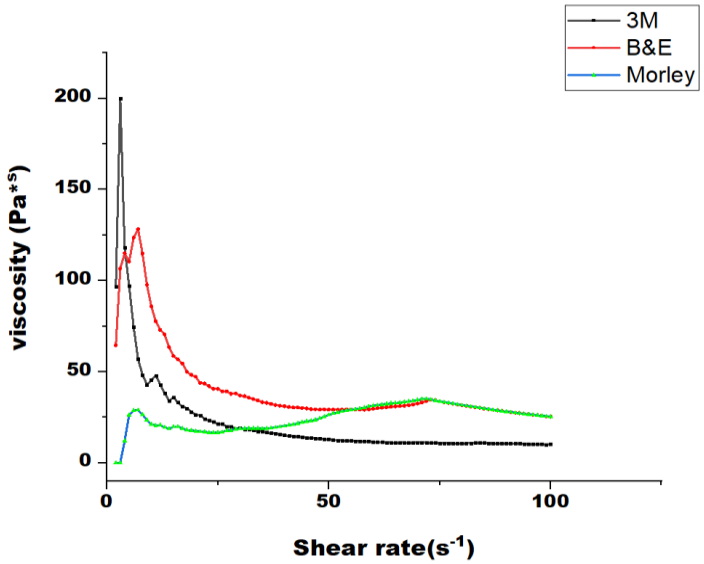


Fig. 3. Shear viscosity profiles of 3M, B&E, and Morley adhesives at 25°C.

Viscosity curves for all bonds can be divided into three distinct zones. In the first zone (0–10 s^{-1}), the shear viscosity, molecular weight, and storage stability ranked from highest to lowest as follows: 3M, B&E, and Morley. The second zone (10–60 s^{-1}), corresponding to the brushing application range, revealed pronounced shear-thinning for the 3M and B&E

bonds, whereas the Morley bond exhibited shear-thickening. In this zone, the viscosity values were approximately 10 Pa·s for 3M, 30 Pa·s for B&E, and 32 Pa·s for Morley. This variation is attributed to the increasing shear rate during application. Finally, in the third zone (60–100 s^{-1}), the viscosity of all three bonds approached an asymptotic value, representing the infinite shear viscosity region.

Figure 4 illustrates that the shear stress of all three adhesives increases with rising shear rate. The 3M and B&E bonds exhibit higher shear stress compared to the Morley bond, which can be attributed to their differing viscosity behaviors, particularly around the brushing shear rate of approximately 60 s^{-1}.

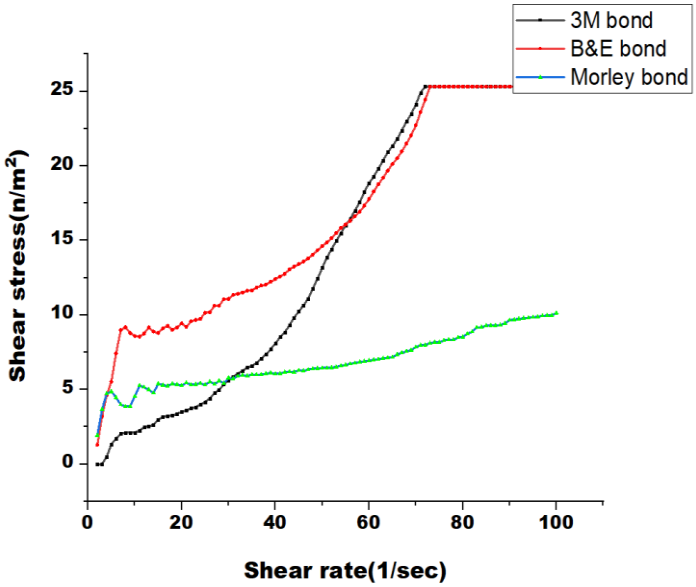


Fig. 4. Flow curves of 3M, B&E, and Morley adhesive bonds at 25°C.

3.2. Non-Newtonian Mathematical Model (Curve Fitting)

The flow index (n) and viscosity consistency (k) for all adhesives were determined using the Rheology Lite program, which applied Power Law, Herschel-Bulkley, Casson, and Bingham models. Among these, the flow behavior of the adhesives best fit the Power Law model. Table 1 presents the n and k values derived from the data shown in Figures 5, 6, and 7. The Power Law Model:

$$\eta = k(\gamma)n - 1 \quad (5)$$

$$\tau = k\,(\gamma)^n \quad (6)$$

Where:

η- is viscosity (Pa. s).

τ- is the shear stress (pa).

γ- is the shear rate (1/s).

n- Flow index.

k- viscosity consistency.

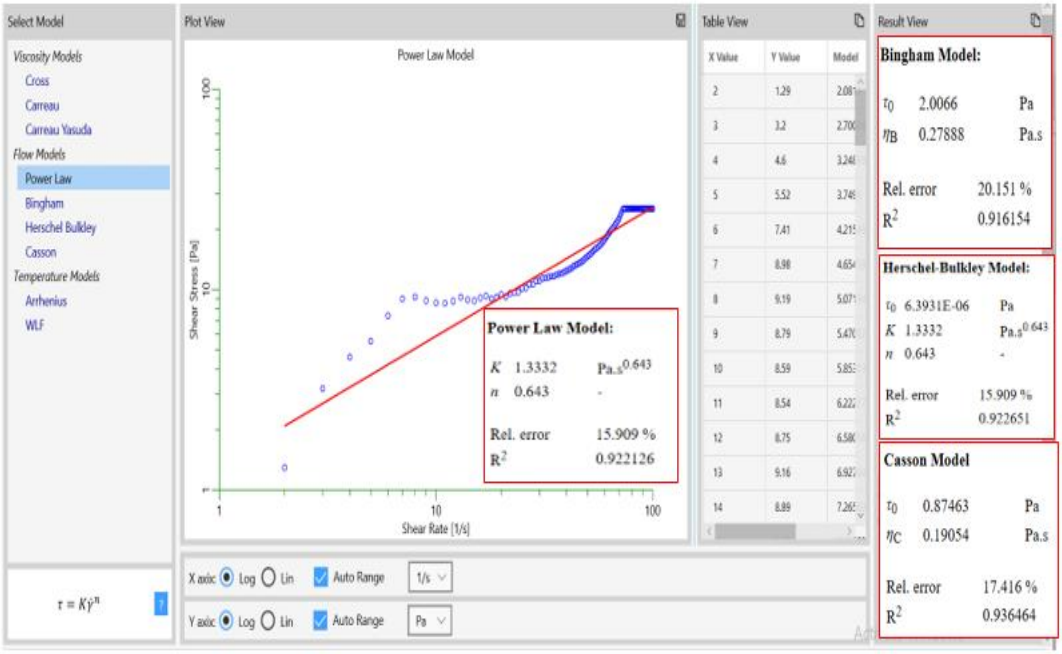


Fig. 5. Curve fitting of the flow behavior of B&E bond at 25°C.

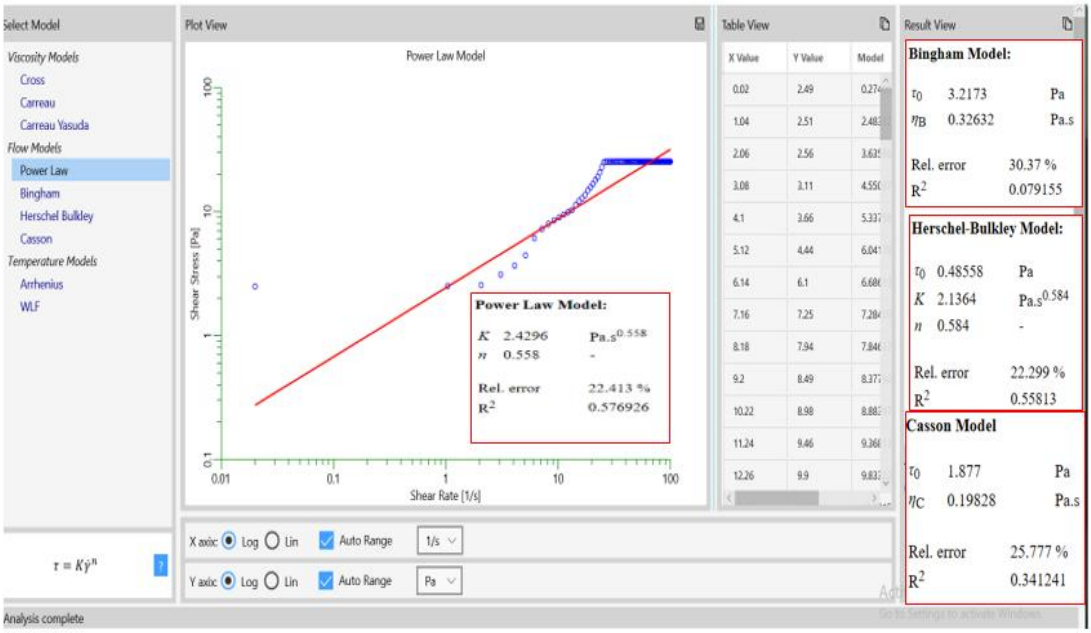


Fig. 6. Curve fitting of the flow behavior of 3M bond at 25°C.

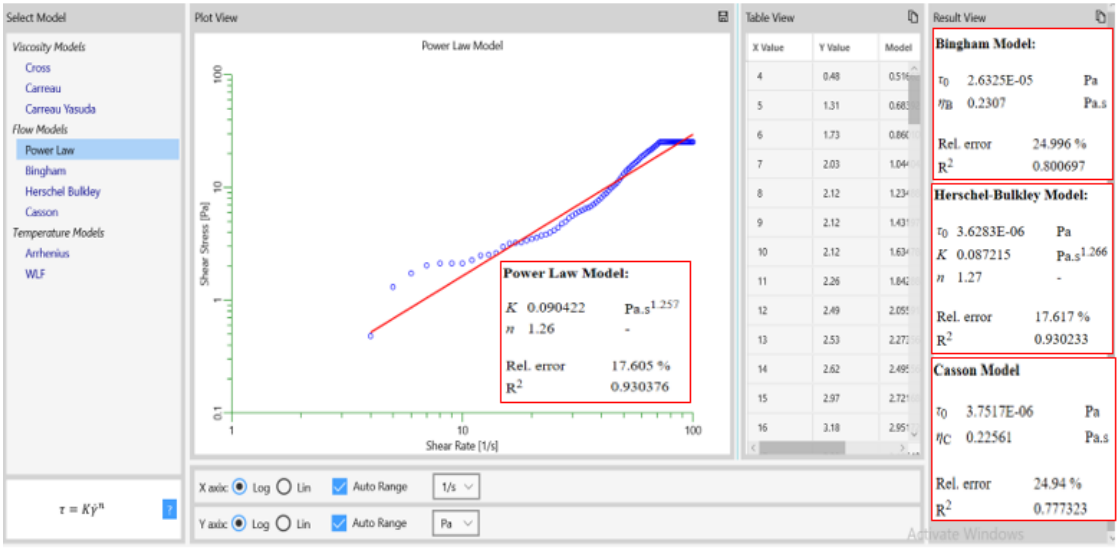


Fig. 7. Curve fitting of the flow behavior of Morley bond at 25°C.

Table 2
Flow index (n) and consistency coefficient (k) of the tested bonding agents.

Adhesive	Flow index (n)	Consistency index (K)
3M bond	0.558	2.4296
B&E bond	0.643	1.3332
Morley bond	1.26	0.090422

Table 2, show that the flow index n of 3M bond was 0.558. This suggests that the viscosity is lower for greater shear rate, implying the bond becomes more fluid-like when stirred or poured. K = 2.4296 suggests that with low shear rates, viscosity is high which shows a thick texture at rest and becomes easier to flow with applied stress. The flow index of B&E was 0.643 which is higher than 3M which means it is less viscous overall and K = 1.3332 constancy B&E viscosity lower than 3M, meaning less resistance to flow at low shear rates. B&E has lower initial viscosity and is easier to flow than 3M under similar conditions. Both bonds exhibit shear thinning behavior. Morley bond flow index of 1.26 was indicative for a shear thickening (Dilatant) fluid. This also means that the viscosity increases with shear rate, thus the bond becomes more solid-like when being agitated or strained. The viscosity constant K was 0.090422, indicating low viscosity at rest. 3M is at its most viscous when it remains still but, when stressed, flows readily. It is this that makes 3M good for adhesives. B&E is similar to 3M but has less viscosity, and therefore better suited for cosmetic purposes. Morley is the contrast to the other two; it exhibits thickening under stress, making it useful for coatings or protective materials that are impact resistant.

3.3. FTIR

In Figure 8, the FTIR spectrum of the Morley bond shows a broad O–H/N–H stretching region between 3757–3873 cm^{-1} and strong C–H/C=O peaks at 2926 and 1720 cm^{-1}. It also exhibits multiple sharp peaks in the fingerprint region (600–1500 cm^{-1}), indicating the highest bond energy absorption. The 3M bond displays O–H/N–H stretching around 3400–3448 cm^{-1} and C–H/C=O absorptions near 2970, 2677, and 2075 cm^{-1}, with fewer sharp peaks in the fingerprint region compared to Morley. In contrast, the B&E bond shows

O–H/N–H stretching from 3749–3950 cm^{-1}, with generally lower peak intensities and most absorptions occurring in lower energy regions.

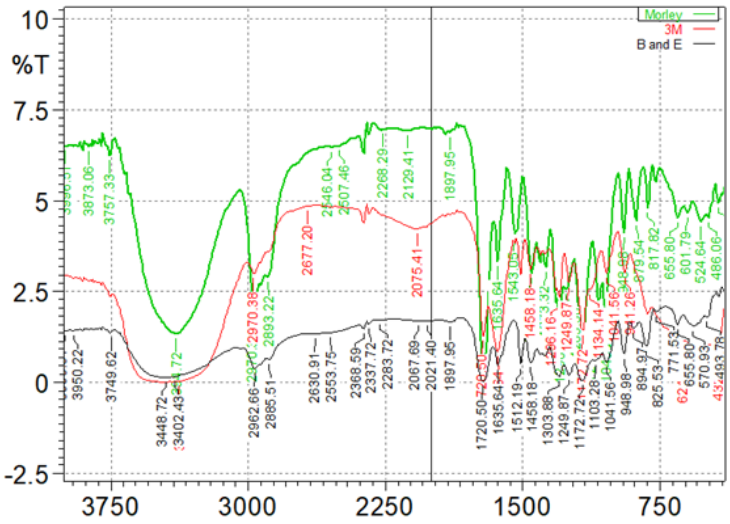


Fig. 8. FTIR spectra showing transmittance percentages for 3M, B&E, and Morley bonding agents.

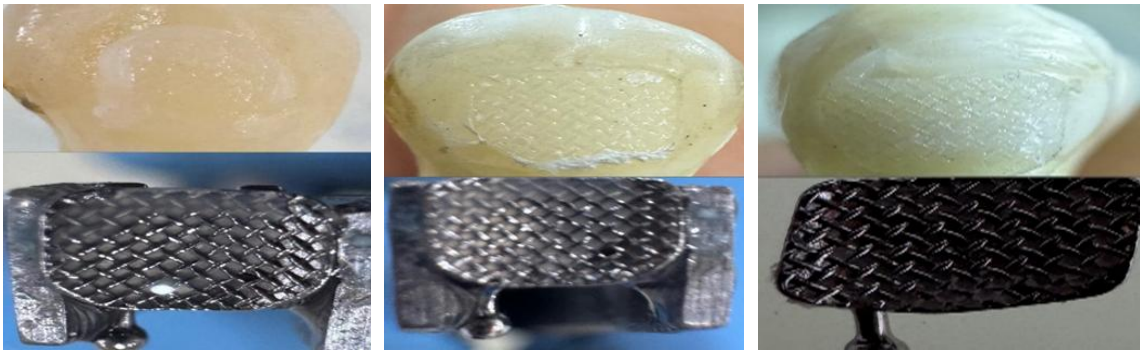
3.4. SBS

According to Table 3, the shear bond strengths of the 2% $Ca_5(PO_4)_3(OH)$/Morley composite using 3M, B&E, and Morley adhesives were 15 MPa, 13.65 MPa, and 11 MPa, respectively. These results demonstrate that shear bond strength increases as shear viscosity decreases and shear stress increases at a shear rate of 60 s^{-1} – conditions that simulate the brushing or application of the adhesive onto the tooth surface. The 3M adhesive exhibited the highest shear bond strength and the lowest viscosity, suggesting better flow and penetration into the composite. In contrast, the Morley adhesive had the lowest bond strength and highest viscosity, indicating reduced flow and weaker adhesion performance, this matches with (Al-Saleh et al., 2021).

Table 3
Shear bond strength of 2% $Ca_5(PO_4)_3(OH)$ composite with 3M, B&E, and Morley adhesives.

Name of Composites	Shear bond strength
2% Ca5(PO4)3(OH) adding to Morley composite, with 3M bond	15 Mpa
2% Ca5(PO4)3(OH) adding to Morley composite, with B&E bond	13.65 Mpa
2% Ca5(PO4)3(OH) adding to Morley composite, with Morley bond	11 Mpa

As illustrated in Figure 9, which shows the failure surface after the adhesion test, it was concluded that the effect of the 3M adhesive did not leave a trace on the tooth surface, which reduces the problems caused by that effect after the end of the period of wear. The amount of adhesive remaining on the tooth surface varied among the three tested bonds. 3M adhesive showed the least material remnants compared to B&E and Morley bonds, and this matches with (Bukhari et al., 2025).



a b c

Fig. 9. Adhesive residues on tooth surfaces after shear bond test where 2%$Ca_5(PO_4)_3(OH)$/Morley composites was used and bonded with A) 3M Adhesive, B) B&E Adhesive, C) Morley adhesive.

This trend is related to its lower shear viscosity what allowed it to penetrated deeper inside the composite. Better penetration, on the other hand, increases adhesive contact between the bracket and enamel surface, resulting in a relatively uniform stress distribution and higher SBS. Therefore, the lower the viscosity, not only leads to better adhesive performance but also less post-debonding residues which is advantageous for enamel integrity and clinical use.

4. CONCLUSIONS

Primers with lower viscosity show better flow characteristics as well as better penetration into the micro porosities of the etched enamel, resulting in a thinner and more uniformly applied adhesive layer. This uniform distribution of the adhesive effectively eliminates internal voids in the resin and allows for a better bond strength during the procedure and a more efficient clean deboning. Also, we outlined that low viscosity products tend to leave less residual adhesive on the enamel surface after the brackets are deboned. Thus, the time necessary for mechanical resin removal (and with that the risk of iatrogenic enamel loss) is less. These refinements further support the clinical significance of the rheological observations and their consequences on the preservation of enamel.

In the present work, a new methodology for optimizing the orthodontic bonding system was investigated by examining the correlation between the flow properties of adhesive and shear bond strength. Viscosity curves and flow curves combined with mathematical fitting by rheological models were used to examine this relationship. The $Ca_5(PO_4)_3(OH)$/Morley (2% by mass) composite systems with 3M and B and E adhesives all exhibited shear thinning (pseudo plastic) behavior, while that using Morley adhesive showed shear thickening behavior. There was an interesting change of shear viscosity as a function in shear rate, such that from the lower shear rate to 60 s^{-1}.

The shear viscosity went from 3M to B and E to Morley in order of lowest to biggest. A reverse relationship between the viscosity and shear bond strength was found, hence a lower viscosity allowed better adhesive penetration into the composite resulting in higher bonding values. For all three adhesives, the Power Law model offered the best match. The 3M adhesive exhibited the lowest degree of shear-thinning characteristics, based on flow behavior index (n), and high consistency index (k) values consistent with being more resistant to changes in viscosity. A higher k value was associated with increased bond strength. FTIR testing revealed that adhesives with stronger O-H and N-H bonds had

higher viscosity. Functional groups interact differently, impacting the rheological and bonding properties of orthodontic adhesives.

ACKNOWLEDGEMENTS

I would like to thank all the professors and colleagues who provided intellectual and academic support during the preparation of this research. I also extend my gratitude to the educational and other institutions that made available the necessary references and materials for this work.

REFERENCES

Aboujaoude, R., Kmeid, R., Gebrael, C., & Amm, E. (2022). Comparison of the accuracy of bracket positioning between direct and digital indirect bonding techniques in the maxillary arch: a three-dimensional study. Progress in Orthodontics, 23(1), 31. DOI: 10.1186/s40510-022-00426-3

Adnan, A., & Agha, N. (2024). Does the Addition of Seashell or Zirconium Oxide Nanoparticles at Different Concentrations Improving Tensile Bond Strength of Orthodontic Adhesive? In-vitro study. Al-Rafidain Dental Journal, 24(2), 331-341. DOI: 10.33899/rdenj.2022.136509.1176

Ahmadian, E., Shahi, S., Yazdani, J., Dizaj, S. M., & Sharifi, S. (2018). Local treatment of the dental caries using nanomaterials. Biomedicine & Pharmacotherapy, 108, 443-447. DOI: 10.1016/j.biopha.2018.09.026

Al-Saleh, S., Alateeq, A., Alshaya, A. H., Al-Qahtani, A. S., Tulbah, H. I., Binhasan, M., ... & Abduljabbar, T. (2021). Influence of TiO2 and ZrO2 nanoparticles on adhesive bond strength and viscosity of dentin polymer: A physical and chemical evaluation. Polymers, 13(21), 3794. ISO 690. DOI: 10.3390/polym13213794

Barkmeier, W. W., & Cooley, R. L. (1992). Laboratory evaluation of adhesive systems. Operative dentistry, 50-61.

Bilen, H. B., & Çokakoğlu, S. (2020). Effects of one-step orthodontic adhesive on microleakage and bracket bond strength: An in vitro comparative study. International orthodontics, 18(2), 366-373. DOI: 10.1016/j.ortho.2020.01.010

Brantley, W. A., & Eliades, T. (2001). Orthodontic materials: scientific and clinical aspects. American Journal of Orthodontics and dentofacial orthopedics, 119(6), 672-673.

Bukhari, K., Alaydaa, R., Alhazmi, R., Alharbi, A., Alahmadi, O., Zafar, M., & Almarhoumi, A. (2025). Comparative analysis of shear bond strength and debonding characteristics of bioactive versus conventional orthodontic adhesives: An in-vitro study. The Saudi Dental Journal, 37(1), 3. ISO 690. DOI: 10.1007/s44445-025-00002-5

Carreau, P. J. (1972). Rheological equations from molecular network theories. Transactions of the Society of Rheology, 16(1), 99-127.

Condò, R., Mampieri, G., Cioffi, A., Cataldi, M. E., Frustaci, I., Giancotti, A., ... & Pasquantonio, G. (2021). Physical and chemical mechanisms involved in adhesion of orthodontic bonding composites: in vitro evaluations. BMC Oral Health, 21(1), 350. DOI: 10.1186/s12903-021-01715-9

Cross, M. M. (1965). Rheology of non-Newtonian fluids: a new flow equation for pseudoplastic systems. Journal of colloid science, 20(5), 417-437. DOI: 10.1016/0095-8522(65)90022-X

Fierascu, R. C. (2022). Incorporation of nanomaterials in glass ionomer cements – recent developments and future perspectives: a narrative review. Nanomaterials, 12(21), 3827. DOI: 10.3390/nano12213827

Frankenberger, R., Lopes, M., Perdigão, J., Ambrose, W. W., & Rosa, B. T. (2002). The use of flowable composites as filled adhesives. Dental materials, 18(3), 227-238. DOI: 10.1016/S0109-5641(01)00040-9

Hadi, N. J., Rydzkowski, T., Ali, Z. S., & Al-Jarwany, Q. A. (2025). Correlations Between Crystallinity, Rheological Behavior, and Short-Term Biodegradation for LDPE/Cellulose Composites with Potential as Packaging Films. Coatings, 15(4), 397. DOI: 10.3390/coatings15040397

Hasan, L. A. (2021). Evaluation the properties of orthodontic adhesive incorporated with nano-hydroxyapatite particles. The Saudi dental journal, 33(8), 1190-1196. DOI: 10.1016/j.sdentj.2021.01.001

Hussein, A. H., & Yassir, Y. A. (2024). Development of a graphene oxide/hydroxyapatite-containing orthodontic primer: An in-vitro study. Materials Chemistry and Physics, 326, 129857. DOI: 10.1016/j.matchemphys.2024.129857

Hwang, C., Choi, M. H., Kim, H. E., Jeong, S. H., & Park, J. U. (2022). Reactive oxygen species-generating hydrogel platform for enhanced antibacterial therapy. NPG Asia Materials, 14(1), 72. DOI: 10.1038/s41427-022-00420-5

Kim, H., Giap, H. V., Kim, K. H., Yu, H. S., Kwon, J. S., Lee, H., & Lee, K. J. (2025). Shear bond strength of zirconia orthodontic brackets depending on surface pretreatment of bonding base. Scientific Reports, 15(1), 38348. DOI: 10.1038/s41598-025-22230-9

Kiryk, S., Kiryk, J., Matys, J., & Dobrzyński, M. (2025). The Influence of Resin Infiltration on the Shear Bond Strength of Orthodontic Brackets: A Systematic Review and Meta-Analysis. Journal of Functional Biomaterials, 16(1), 32. DOI: 10.3390/jfb16010032

Knox, J., Jones, M. L., Hubsch, P., & Middleton, J. (2000). The influence of orthodontic adhesive properties on the quality of orthodontic attachment. The Angle Orthodontist, 70(3), 241-246. DOI: 10.1043/0003-3219(2000)070%3C0241:TIOOAP%3E2.0.CO;2

Kux, B. J., Bacigalupo, L. M., Scriba, A., Emmrich, M., & Jost-Brinkmann, P. G. (2022). Elution study of acrylic monomers from orthodontic materials using high performance liquid chromatography (HPLC). Journal of Orofacial Orthopedics/Fortschritte der Kieferorthopädie, 83(1), 34-47. DOI: 10.1007/s00056-021-00292-4

Nikpour, S., Shahroudi, A. S., Saffarpour, A., Akhavan, A., & Sodagar, A. (2021). Shear Bond Strength of Self-Adhesive Composite Containing TiO2 and SiO2 Nanoparticles with an Additional Etching Step for Orthodontic Brackets Bonding to Enamel. Folia Medica, 63(6), 865-874. DOI: 10.3897/folmed.63.e56657

Par, M., Gotovac, L., Horvat, S., Marovic, D., Tarle, Z., Tauböck, T. T., ... & Panduric, V. (2025). Comparing ISO 4049 and Fourier-transform infrared spectroscopy for assessing ambient light sensitivity in dental resin composites. Scientific reports, 15(1), 8455. DOI: 10.1038/s41598-025-93088-0

Priyadarsini, S., Mukherjee, S., & Mishra, M. (2018). Nanoparticles used in dentistry: A review. Journal of oral biology and craniofacial research, 8(1), 58-67. DOI: 10.1016/j.jobcr.2017.12.004

Sayed, M. E. (2025). Comparative Evaluation of Shear Bond Strength of Aesthetic Orthodontic Brackets Bonded to Aged Composite Restorative Resin Materials. Polymers, 17(5), 621. DOI: 10.3390/polym17050621

Seyedmajidi, S., Rajabnia, R., & Seyedmajidi, M. (2018). Evaluation of antibacterial properties of hydroxyapatite/bioactive glass and fluorapatite/bioactive glass nanocomposite foams as a cellular scaffold of bone tissue. Journal of Laboratory Physicians, 10(03), 265-270. DOI: 10.4103/JLP.JLP_167_17

Sharifi, N., Mohammadi, Z., Arab, S., Shojaee, M., Vafadoost, F., & Zakerzadeh, A. (2022). Shear bond strength of orthodontic brackets bonded with a self-adhering composite in dry and saliva-contaminated conditions. Frontiers in Dentistry, 19, 5. DOI: 10.18502/fid.v19i5.8548

Wiertelak-Makała, K., Szymczak-Pajor, I., Bociong, K., & Śliwińska, A. (2023). Considerations about cytotoxicity of resin-based composite dental materials: A systematic review. International Journal of Molecular Sciences, 25(1), 152. DOI: 10.3390/ijms25010152

Yan, J., Sun, H., Liu, Z., Yang, Z., Luo, T., Liao, X., ... & Hua, F. (2025). Fluorescent Orthodontic Adhesive With APTES-Modified ZnO Quantum Dots: Bond Strength, Cytocompatibility, and Clinical Feasibility. Orthodontics & Craniofacial Research. ISO 690. DOI: 10.1111/ocr.12932

Zaki, S. S., Ghorab, S. M., & Shamaa, M. S. (2023). Antioxidant effect on shear bond strength of orthodontic brackets after tooth bleaching: a scoping review of in vitro studies. International Orthodontics, 21(3), 100777. DOI: 10.1016/j.ortho.2023.100777