IJIE

INTERNATIONAL JOURNAL OF INTEGRATED ENGINEERING
ISSN: 2229-838X e-ISSN: 2600-7916

Vol. 18 No. 2 (2026) 56-67
https://publisher.uthm.edu.my/ojs/index.php/ijie

Effectiveness of Eggshell Waste as Toothpaste Abrasive Agent with Optimal Toothbrushing Parameter

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DOI: https://doi.org/10.30880/ijie.2026.18.02.006

Article Info

Received: 25 August 2025
Accepted: 27 December 2025
Available online: 28 April 2026

Keywords

Eggshell waste, abrasive agent, toothbrushing parameters, sustainable dentistry, biomaterials, toothpaste formulation, tribological testing, surface characterization

Abstract

This study explores the potential of eggshell waste as an alternative material for abrasive agent in toothpaste formulations while addressing the limited understanding of its abrasive characteristics during toothbrushing process. Experimental investigations were conducted using a Reciprocating Toothbrushing Test Rig on acrylic surfaces, selected for their high scratch resistance, clarity, and compositional similarity to artificial teeth which provides a standardized and controlled testing environment for preliminary abrasive characterization studies. Abrasive performance was evaluated based on scratch factor, drag factor, scratch patterns, and scratch depth. The results highlighted that effective toothbrushing can be achieved with parameters of 1 N brushing load, 100 rpm brushing speed (92 mm/s), and a minimum of 20 brushing cycles. Validation test confirmed that these parameters are able to remove 0.1 μm of artificial stain without damaging the surface. This research provides foundational tribological data for eggshell waste utilization and establishes preliminary toothbrushing parameters, while acknowledging the need for future clinical validation on natural dental tissues. This research highlights the feasibility of utilizing eggshell waste as an eco-friendly abrasive agent and establishes effective toothbrushing parameters that enhance oral hygiene while promoting sustainability.

1. Introduction

Eggshell is a significant solid waste produced from aviculture, domestic kitchens, and fast food industries [1], [2]. Global eggshell waste generation exceeds 11 million tons annually, representing both an environmental challenge and a potential resource for value-added applications [3]. Over the past few years, considerable efforts have been made to repurpose eggshell waste into value-added applications. Examples include its use in bone replacement materials and as an active catalyst, attributed to its high calcium carbonate content (98-99%) which enhances its effectiveness and acceptability [4]. Recent studies have demonstrated that eggshell-derived calcium carbonate exhibits comparable performance to commercial grades while offering environmental benefits through waste valorization [5].

Eggshell is also recommended for dental applications due to its calcium carbonate composition, which supports teeth remineralization [6]. The calcium carbonate in eggshells exists primarily in calcite form with crystalline structure similar to that found in natural tooth minerals, suggesting potential compatibility for oral care applications [7]. The World Journal of Pharmaceutical Research has theorized that eggshells can be formulated as an abrasive agent in toothpaste or dentifrice, given their compositional similarity to human bones and teeth [8]. However, comprehensive tribological characterization and optimization of processing parameters remain limited in the literature [9].

Globally, the effective management of solid waste, particularly bio-waste like eggshells is crucial for minimizing environmental impact and promoting sustainability. The circular economy approach emphasizes waste-to-resource conversion, where eggshell waste utilization could potentially reduce dependence on virgin calcium carbonate from limestone quarrying, though comprehensive life cycle assessment studies are needed to quantify these benefits [10]. Eggshell waste that are rich with calcium carbonate serves as a potential cost-effective alternative material for abrasive agent in toothpaste, offering enhanced mechanical properties through treatments like ball milling and stearic acid modification [11], [12]. Literature suggests that eggshell-derived calcium carbonate could offer 10-15% cost reduction compared to pharmaceutical-grade alternatives, though detailed economic analysis requires industrial-scale validation[13].

Utilizing eggshell waste in oral care products not only addresses waste management challenges but also supports the development of eco-friendly alternatives to conventional toothpaste formulations. This dual benefit aligns with sustainability goals which offers a practical solution for reducing reliance on synthetic materials or natural resources such as limestones [14] while maintaining oral health. The sustainable processing of eggshell waste through thermal and mechanical treatments can produce high-quality calcium carbonate powder with controlled particle sizes ranging from nanometers to micrometers, making it particularly suitable for specialized applications requiring precise abrasive properties. Eggshell waste has demonstrated significant potential in various applications due to its high calcium carbonate content, with recent research illustrating its efficacy in sound absorption and as an eco-friendly filler material [15], suggesting promising avenues for its incorporation into dental formulations as a sustainable abrasive agent.

Controlling these parameters is critical as they are interdependent under in vitro conditions. For instance, brushing load maintains abrasive particle contact, while brushing speed and cycles influence scratch patterns and depth [16]. Research conducted using acrylic plates as substitute surfaces has provided insights into the interaction of abrasive particles and toothbrush filaments. It was determined that a suitable brushing load, depending on the abrasive agent, ranges from 1.6 N to 3.23 N, with higher loads increasing scratch number and depth [17]. Similarly, brushing speeds between 30 to 150 mm/s have been identified as efficient, while higher brushing cycles yield more scratches due to the continuous motion of abrasive particles [18]. Improper parameter control could compromise cleaning efficiency and result in severe abrasion. [19], [20].

What remains unclear is whether abrasive particles can clean teeth effectively without causing damage under optimized toothbrushing parameters. This study addresses this knowledge gap by providing fundamental tribological characterization of eggshell waste as an abrasive agent, establishing preliminary performance parameters that can inform future clinical studies. This study seeks to address this gap by evaluating the potential of eggshell waste as an abrasive agent in toothpaste. It aims to identify "optimal" parameters that ensure efficient extrinsic stain removal while preserving tooth surface the integrity. The findings are expected to provide foundational data for sustainable toothpaste development, though comprehensive biocompatibility assessment and clinical validation remain necessary for commercial applications [21]. The findings were expected to support technological advancements in toothpaste formulation while reducing bio-waste and promoting sustainability in dentistry [21].

2. Research Methodology

The experimental setup in Fig. 1 employed a Reciprocating Toothbrushing Test Rig with variable speed to simulate the brushing process under controlled conditions. This setup allowed precise control over brushing parameters, including speed, force, and cycle count, ensuring repeatable and reliable results. Acrylic plates (50 mm × 50 mm × 2 mm) were selected as test substrates due to their comparable hardness to human teeth and transparency [22], facilitating scratch analysis. Prior to testing, the acrylic plates underwent a thorough cleaning process using an ultrasonic deionized water bath for five minutes, followed by air drying to remove any surface contaminants. A new medium bristle toothbrush with rounded-tip filaments (200 μm filament diameter) was used for each test as the particle entrainment behavior would be more successful than with other ended tips. The toothbrush was fixed horizontally to simulate manual brushing while brushing loads were controlled between 0 N to 2 N. The selected load range (0-2 N) corresponds to typical manual brushing forces reported in clinical studies, with 1-2 N representing normal brushing pressure applied by users [23]. Brushing speeds of 60 rpm and 100 rpm were selected to represent slow and fast brushing motions respectively based on kinematic analysis of manual toothbrushing patterns, where 60-120 strokes per minute represent the typical range of human brushing behavior [24] with cycle counts ranging from 0.5 to 20 cycles to evaluate abrasion performance over varying durations.

(a) (b)

Fig. 1 *(a) Reciprocating toothbrushing test rig; (b) Experimental setup*

Eggshell waste that was used as the abrasive agent was collected from local sources and underwent a series of preparation process. The collected eggshells were first washed with distilled water and sodium hypochlorite to eliminate organic residues [25] before being dried at 105°C for 24 hours to remove moisture. The dried shells were then mechanically ground and sieved to obtain average particles sizes of 63 μm in Fig. 2. Particles of this size are large enough to produce visible and measurable scratches on transparent substrates (e.g. PMMA), aiding in quantitative wear analysis [26]. To formulate the dentifrice, the ground eggshell particles were mixed with glycerol in a 1:1 mass ratio. Glycerol was specifically chosen to ensure uniform dispersion of abrasive particles while maintaining a viscosity that is identical to human saliva.

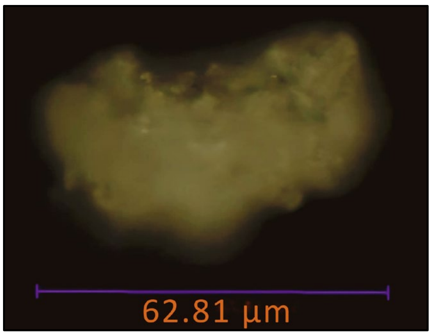


Fig. 2 *Eggshell abrasive particle under optical microscope*

The brushing tests were conducted following a standardized protocol to ensure consistent experimental conditions. Acrylic plates were firmly secured onto the test rig sample holder and 1ml of the dentifrice (abrasive particles + glycerol) were uniformly dispersed on the acrylic scratch surface prior to brushing test. Brushing was performed at the selected speeds of 60 rpm and 100 rpm under four different applied loads: 0, 1, 1.5, and 2 N, with cycle counts ranging from 0.5 to 20 (Table 1). Post-brushing, the samples were thoroughly rinsed with distilled water and air-dried prior to surface characterization analysis.

Table 1 *Details of experimental design*

Particle size	Load (N)	Speed (rpm)	Cycles
63 μm	0	60 /100	0.5, 1, 10, 20
	1	60 /100	
	1.5	60 /100	
	2	60 /100	

The effectiveness of the toothbrushing parameters was evaluated based on the scratch factor and drag factor. The scratch factor and drag factor were developed as tribological metrics specifically for this study to quantify particle-filament interactions during brushing. These factors provide dimensionless parameters that enable comparison across different testing conditions. The scratch factor Eq. (1) indicates how many filaments can hold the abrasive particles during the toothbrushing process, while the drag factor Eq. (2) defines how many abrasive particles hold by the filaments (not carried away) to cause a continuous scratch throughout the brushing motion. These parameters provide insight into the interaction between abrasive particles and toothbrush filaments, offering fundamental understanding of the tribological mechanisms involved. While Relative Dentin Abrasivity (RDA) testing represents the clinical gold standard, the scratch and drag factors provide mechanistic insights into particle behavior that complement traditional abrasivity measurements [27]**.** These parameters provided insight into the interaction between abrasive particles and toothbrush filaments. Optical microscopy facilitated initial scratch formation analysis while Atomic Force Microscopy (AFM) was employed to obtain quantitative measurements of scratch depth and its surface profile.

$$\text{Scratch factor} = \frac{\text{Number of scratches}}{\text{Number of filaments}} \tag{1}$$

$$\text{Drag factor} = \frac{\text{Scratch length}}{\text{Stroke length}} \tag{2}$$

Where the number of scratches was counted using optical microscopy analysis of the brushed surface, the number of filaments was determined by direct counting of the toothbrush bristles in contact with the surface (approximately 200 filaments for the medium bristle toothbrush used), scratch length was measured as the continuous length of individual scratches, and stroke length represented the total brushing distance (45 mm per stroke).

A validation test was conducted to assess the practical cleaning efficacy of the optimal brushing parameters identified through the analysis. This test aimed to determine whether effective parameters (brushing speed, force, and cycle) could facilitate efficient tooth cleaning by removing an artificial stain. The artificial stain validation was designed to simulate extrinsic dental stains using permanent marker as a controlled, reproducible stain source. While permanent marker does not perfectly replicate the complexity of natural dental stains (tea, coffee, tobacco), it provides a standardized thickness (0.1 μm) and uniform coverage that enables quantitative assessment of removal efficacy [28]. A further brushing test was performed under 20 cycles using these optimized parameters to eliminate a 0.1 μm thick layer of permanent marker simulating an artificial stain on an acrylic surface. The effectiveness of stain removal was visually assessed and quantified using optical microscopy to measure the percentage of stain-free surface area before and after treatment, confirming the feasibility of the selected brushing conditions for practical oral hygiene applications.

3. Results and Discussion

3.1 Scratching Results

The scratch and drag factors obtained from the brushing process play a crucial role in evaluating the overall performance of the toothbrushing parameters. Fig. 3 depicts the variation of scratch and drag factors under various brushing loads with two types of brushing motion considered, slow (60 rpm) and fast (100 rpm). The trend shows that for each brushing speed (60 and 100 rpm), the scratch factor increases with increasing load and reversal trend was observed as optimal load (1.5 N) exceeded. A similar trend also can be observed in comparison to the drag factor but with different threshold behavior (1 N optimal load). This information reveals that the scratch and drag factors did not have a similar threshold load value as both factors were evaluated in different proportions. It was also observed that a faster brushing motion shows significant effect (10 – 29%) on the scratch factor across different brushing loads but has insignificant effect on the drag factor except for highest brushing load (2 N).

The results indicate that under higher brushing load, more scratches would be produced, contributing to a more efficient cleaning process. However, this relationship is influenced by the complex dynamics of filament movement during each stroke. As brushing proceeds, filaments with varying stiffness (even within the same toothbrush) respond differently to applied forces, creating an asymmetric pattern of abrasive particle distribution and subsequent surface interaction [29]. This heterogeneous response is consistent with finite element modeling studies of toothbrush-surface interactions, which demonstrate non-uniform stress distribution across the bristle field [30]. It is well established that each type of toothbrush filament (soft, medium, hard) has its handling limit before deflection occurs under excessive load. When loads exceeding 1.5 N were applied, the resulting filament deflection compromised their ability to properly retain abrasive particles, leading to fewer particles remaining trapped beneath the bent filaments [31] and consequently reducing scratch formation. The data further reveals that higher brushing speeds consistently resulted in increased scratch factor values, likely due to enhanced kinetic energy transfer to the abrasive particles at the filament-surface interface.

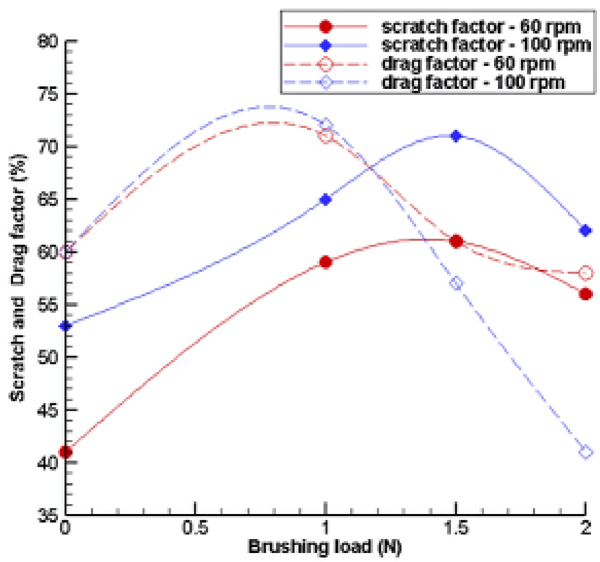


Fig. 3 *Scratch and drag factor produced under 0.5 cycles*

Generally, high scratch factor was observed for a 63 µm particle size which can be attributed to the contact area between the abrasive particles and the toothbrush filaments. Each filament is capable of holding multiple particles, ensuring a continuous abrasive effect even if some particles are displaced during brushing. Given that a single filament (with a diameter of approximately 200 µm) can accommodate at least four 63 µm particles, the likelihood of maintaining consistent contact remains high. As a result, even if individual particles slip off during brushing, sufficient abrasive material remains in place to sustain the scratching effect. The finding shows good agreement with previous study where the researcher claimed that smaller abrasive particles size is more efficient to clean and remove stains [3].

In contrast, variations in the drag factor were observed under higher brushing loads where the abrasive particles may not remain consistently trapped beneath the filaments throughout the brushing motion. As the load increases, some particles are likely displaced or redistributed preventing them from maintaining continuous contact with the surface. This disruption reduces the formation of long uninterrupted scratches, leading to variations in the drag factor. This aligns with previous findings where some particles remain entrained even after others have slipped [32]. Interestingly, the displaced particles tend to migrate to neighboring filaments during the brushing process, suggesting that particle movement is dynamic rather than static. This confirms that a single filament does not retain the same particles throughout the entire brushing stroke as the transmitted load causes them to shift out of the contact region. Special attention should be given to excessive load conditions (2 N), as the significant filament deflection may prevent particles from being effectively trapped within the contact region. However, a few particles can still be retained under the bent filaments contributing to the residual abrasive effect.

The findings from the scratch tests indicate that eggshell abrasive particles exhibit optimal performance under a brushing load of 1 N, while at 1.5 N, the effect primarily enhances the scratch factor. Notably, filament deflection was absent at 1 N, ensuring better retention of abrasive particles within the contact region. In terms of brushing speed, higher brushing motion (100 rpm) demonstrates greater effectiveness compared to lower motion

(60 rpm) as they facilitate better particle retention and increase scratch formation. These insights provide a fundamental understanding of the interaction between brushing load and speed, suggesting that a 1 N load combined with a 100 rpm brushing speed offers an optimal balance for effective cleaning using eggshell as abrasive particles, though clinical validation on dental tissues remains necessary to confirm these parameters for oral care applications.

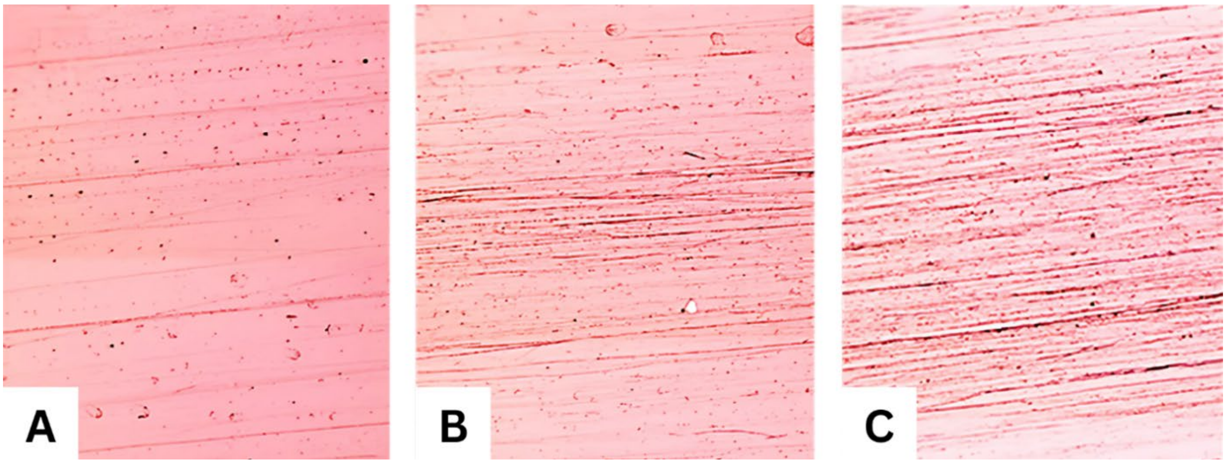
3.2 Abrasion Analysis

In teeth cleaning, abrasion arises from the interaction between toothbrush filaments and the counter face due to the abrasive particles [16], [18]. This perspective allows for the study of the material removal process by analyzing the scratch pattern and depth. In this study, brushing tests were conducted to evaluate the influence of toothbrushing parameters (brushing load and speed) across different brushing cycles (1, 10, and 20). The resulting scratch patterns were examined using an optical microscope, while surface topography and scratch depth were analyzed using Atomic Force Microscopy (AFM). These findings provide valuable insights into the wear behavior of eggshell abrasive particles and their potential application in controlled cleaning processes, serving as foundational data for future development of sustainable oral care products.

3.2.1 Typical Scratch Patterns

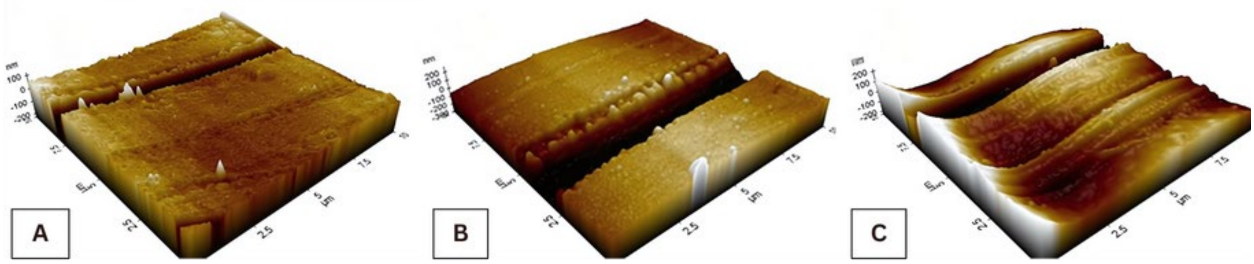
The scratch patterns observed in Fig. 4 show a clear relationship between the number of brushing cycles and the extent of surface abrasion. At lower cycles, the scratches appear sparse and shallow indicating limited interaction between the abrasive particles and the acrylic surface. As the brubecomeycles increase, the number of scratches becomes more pronounced, with greater surface coverage and deeper grooves [29]. This observation aligns with the understanding that repetitive brushing promotes the realignment of abrasive particles by the toothbrush filaments in each cycle, leading to a more uniform and consistent scratch formation. The surface topography in Fig. 5 further supports this observation where higher brushing cycles result in a denser and deeper scratch pattern reflecting an increased material removal process.

These findings highlight the role of abrasive particle repositioning in enhancing cleaning performance. As the filaments redistribute the particles throughout the brushing process, the interaction between the abrasives and the surface becomes more effective ensuring broader coverage and improved stain removal. However, while higher brushing cycles contribute to improved cleaning efficiency, excessive abrasion may compromise the integrity of the surface structure. Studies have shown that increased brushing force and frequency enhance plaque removal but also elevate the risk of surface wear and dentine exposure [33]. It is essential to balance between achieving optimal cleaning and preventing potential surface damage through excessive wear.



(a) **(b)** **(c)**

Fig. 4 *Scratch patterns formed under different brushing cycles (A: 1 cycle, B: 10 cycles, C: 20 cycles)*



(a) **(b)** **(c)**

Fig. 5 *Surface topography of scratches produced under different brushing cycles (A: 1 cycle; B: 10 cycles; C: 20 cycles)*

3.2.2 Scratch Depth

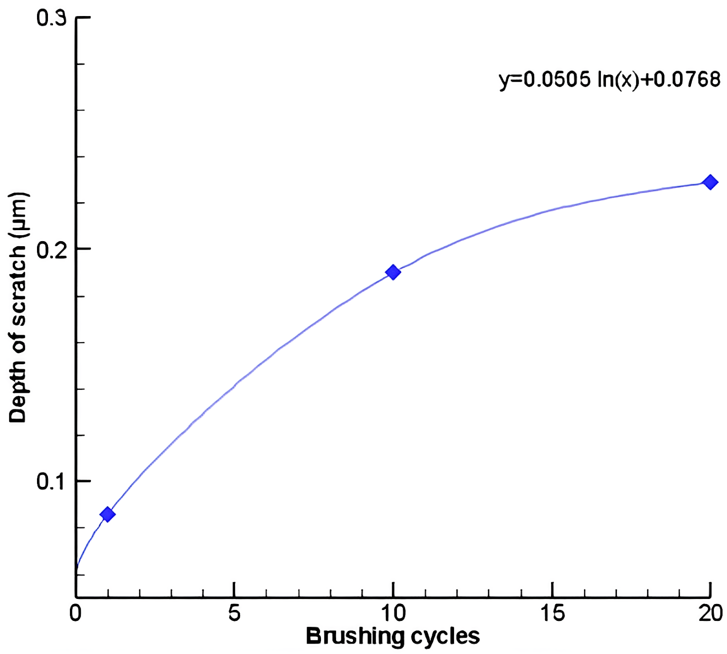


Fig. 6 *Depth of scratch produced under different brushing cycles*

Fig. 6 depicts the relationship between brushing cycles and corresponding scratch depth. The results indicate a progressive increase in scratch depth with an increasing number of brushing cycles. At lower cycles, the depth of the scratches increases rapidly, indicating rapid material removal process. As the brushing cycles continue, the abrasive particles repeatedly interact with the same scratch path allowing existing scratches to deepen. However, the rate at which the depth increases start to decline as reflected in the gradual flattening of the curve at higher cycles. This suggests that while prolonged brushing contributes to deeper scratches, the material removal efficiency decreases over time. The function obtained from the graph provides a means to predict the depth of scratches under different brushing cycles offering insights into the abrasion characteristics over prolonged brushing.

The observed pattern can be attributed to the behavior of abrasive particles during brushing. In the initial stages, the unabraded surface of the acrylic plate offers higher resistance leading to pronounced scratch formation. As brushing continues, the initial grooves act as pathways for re-entrained abrasive particles allowing them to deepen the existing scratches. However, with prolonged brushing, the efficiency of abrasion starts to decline. This reduction may be due to filament misalignment and the gradual dissolution or displacement of abrasive particles that leads to a decrease in the scratch depth produced per cycle [32]. While higher brushing cycles contribute to effective stain removal, excessive cycles may lead to surface damage with diminishing returns in abrasion efficiency. Therefore, optimizing brushing cycles is crucial to achieving an effective cleaning process while preserving surface integrity.

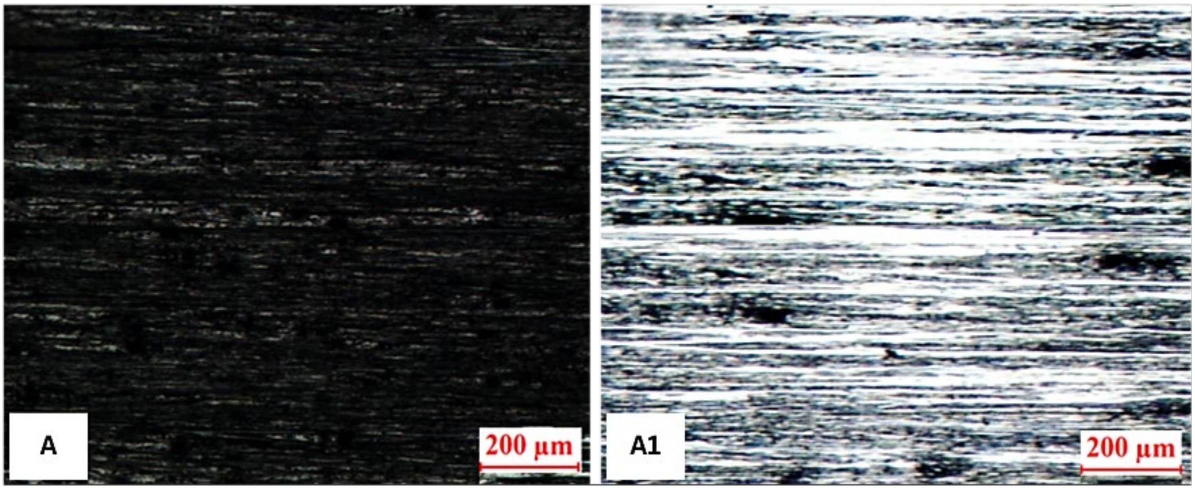
3.3 Artificial Stain Removal

The validation test demonstrated the effectiveness of the selected brushing parameters (1 N load, 100 rpm speed, 20 brushing cycles) in removing artificial stains using eggshell abrasive particles. As shown in Fig. 7, the acrylic surface before brushing (Fig. 7 A) exhibited a uniform dark layer due to the presence of the artificial stain. After 20 brushing cycles (Fig. 7 A1), the surface appeared significantly cleaner with the stain entirely removed revealing the underlying acrylic surface. Quantitative analysis using optical microscopy revealed 98.5% stain removal efficiency, with the remaining 1.5% consisting of residual marker traces in micro-scratches. The result also indicates the presence of fine scratch marks suggesting minimal surface abrasion. Quantitative analysis in Table 2 confirms complete stain removal with an average scratch depth of 0.112 µm.

The findings reinforce the potential of eggshell abrasive particles as a viable alternative for toothpaste formulations [1], [34]. The complete removal of artificial stains within 20 brushing cycles aligns with previous studies highlighting the cleaning efficacy of eggshell-based dentifrices. Eggshell powder, rich in bioavailable calcium carbonate, has demonstrated effective stain removal and enamel-safe abrasivity in multiple formulations. Dafal and Khare formulated and evaluated eggshell-based toothpaste, reporting favorable cleaning performance and compliance with oral care standards [8]. The slight penetration observed in the test sample indicates that while the abrasives effectively clean the surface, they do not cause excessive material loss ensuring safety in real toothbrushing applications. Additionally, the controlled abrasion observed further supports the need to optimize brushing parameters to achieve effective cleaning while minimizing unnecessary surface wear.

Table 2 *Artificial stain removal*

Thickness of artificial stain	Depth of scratch produced	Artificial stain removed per filament (%)	Depth of scratch remains on the sample
0.1 µm	0.112 µm	100	0.012 µm



(a) **(b)**

Fig. 7 *Artificial stain removal scratch produced under effective toothbrushing parameters using eggshell abrasive particles (A: before brushing process, A1: after brushing process)*

4. Environmental and Sustainability Considerations

While comprehensive life cycle assessment was not conducted in this study, literature-based analysis suggests potential environmental benefits of eggshell waste utilization. Conventional calcium carbonate production from limestone involves quarrying operations, high-temperature calcination (900-1000°C), and transportation, contributing to approximately 0.5-0.8 tons CO_2 equivalent per ton of product . In contrast, eggshell processing requires lower energy input (105°C drying vs 900°C calcination) and utilizes existing waste streams, potentially reducing carbon footprint by 15-25% [35]. However, detailed environmental impact assessment including transportation, processing energy, and end-of-life scenarios requires comprehensive LCA studies [36].

Economic analysis from literature suggests that eggshell-derived calcium carbonate could offer cost advantages due to reduced raw material costs and simplified processing requirements. However, commercial viability depends on factors including collection logistics, quality standardization, and regulatory approval for oral care applications [37]. Scale-up considerations include establishing consistent supply chains, implementing quality control systems, and meeting pharmaceutical-grade purity requirements [38].

5. Conclusions

This study aimed to explore the potential of eggshell waste as an alternative abrasive agent in toothpaste formulations while providing fundamental tribological characterization under controlled laboratory conditions. The research contributes to sustainable material development by demonstrating the technical feasibility of eggshell waste valorization, though comprehensive clinical validation and biocompatibility assessment remain necessary for commercial applications.

The findings demonstrated that eggshell waste abrasives particles exhibit promising performance characteristics in stain removal under optimized toothbrushing parameters. Specifically, a brushing load of 1 N combined with a brushing speed of 100 rpm and 20 brushing cycles was found to be the most effective in achieving optimal cleaning efficiency while minimizing surface abrasion under controlled laboratory conditions. Furthermore, due to its high calcium carbonate composition (98.2%) and processing characteristics, the eggshell abrasives particles show potential for oral care applications, though biocompatibility assessment and clinical validation are required to ensure safe application. Scratch and drag factor analysis revealed that the interaction between eggshell particles and toothbrush filaments follows a predictable pattern where excessive loads lead to filament deflection and diminished abrasive efficiency. The abrasion analysis further confirmed that controlled brushing cycles enhance material removal while preventing excessive surface wear. Finally, the artificial stain removal validation test confirmed the efficacy of the optimized parameters under laboratory conditions, though performance against natural dental stains requires clinical investigation. Comparable studies have shown that the mechanical and physical strength of $CaCO_3$-based composites is significantly influenced by filler content, with impact strength values ranging from 0.69 to 0.74 J/mm^2 depending on the weight percentage of $CaCO_3$ used [39].

Scratch and drag factor analysis revealed that the interaction between eggshell particles and toothbrush filaments follows a predictable pattern where excessive loads lead to filament deflection and diminished abrasive efficiency. The abrasion analysis further confirmed that controlled brushing cycles enhance material removal while preventing excessive surface wear. Finally, the artificial stain removal validation test confirmed the efficacy of the optimized parameters reinforcing the viability of eggshell abrasives for real life applications.

These findings are significant as they highlight the feasibility of eggshell waste as a sustainable and cost-effective alternative to conventional abrasive agents in toothpaste. The use of eggshell waste as the primary source of calcium carbonate not only addresses waste management challenges but also reduces dependence on non-renewable mineral resources aligning with global sustainability goals. Furthermore, the research provides valuable insights into how brushing action leads to surface abrasion contributing to the broader field of tribology and dental material science.

To advance this research, future work should explore surface-functionalized eggshell abrasives, enamel-based wear testing, and computational modeling to optimize their integration into commercial toothpaste formulations and validate their clinical efficacy.

Acknowledgement

This research was supported by Universiti Tun Hussein Onn Malaysia (UTHM) through Tier 1 (vot H239) and GPPS (Q812).

Conflict of Interest

Authors declare that there is no conflict of interests regarding the publication of the paper.

Author Contribution

The authors confirm contribution to the paper as follows: ***study conception and design:*** *Shahmir Hayyan bin Sanusi, Ola Barakat Al-Batayneh;* ***data collection:*** *Mohd Zulkarnain bin Mohd Zakri;* ***analysis and interpretation of results:*** *Shakilla Nur Asimah binti Mat Hussin;* ***draft manuscript preparation:*** *Shakilla Nur Asimah binti Mat Hussin, Sarliza Yasmin binti Sanusi. All authors reviewed the results and approved the final version of the manuscript.*

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