Research Progress in Mechanical and Manufacturing Engineering Vol. 3 No. 1 (2022) 862-874
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RPMME

Homepage: http://publisher.uthm.edu.my/periodicals/index.php/rpmme
e-ISSN : 2773-4765

A Review on The Efficacy of Seashell's Waste as Alternative Abrasive Agent in Toothpaste

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DOI: https://doi.org/10.30880/rpmme.2022.03.01.092
Received 01 December 2021; Accepted 01 April 2022; Available online 30 July 2022

Abstract: While the ingredients may differ slightly, toothpastes from all brands overall contain the same general ingredients which are mild abrasive, binders, humectants, flavouring agents, sweeteners, colouring agents, preservatives, active ingredients and others. The abrasive specifically is made up of different types depending on the company's designation and one of it being the calcium carbonate. Calcium carbonate can be found in chalk, limestone, marbles and seashells. Seashells is a type of mollusc that contains very high calcium carbonate content ranging from 95% to 98%. In seashells harvesting districts, it is found that abundance of seashell waste is being heaped by the beach and causing pollutions such as soil pollution and odour pollution. This thesis studies the significant and effectiveness of using seashell waste as alternative abrasive agent for toothpaste. Different type of mollusc were used to represent the seashells and they are mussels, clam, oyster and cockle. From the results obtained, all of them shows very similar results and the final test which is the validation test, clearly proves that using seashells as abrasive agent are efficient in removing stains on the teeth as the depth scratch made by all the different seashells are deeper than the thickness of the artificial stain which represents the actual teeth stains.

Keywords: Seashell, Abrasive Agent, Calcium Carbonate

1. Introduction

In 2015, all of the United Nation Members agrees to adopt the 2030 Agenda for Sustainable Development Goals (SDGs) where its main mission is to provide a shared blueprint for peace and prosperity for people and the planet, now and into the future. One of the goals of the SDGs is 'Life below Water' which has its own specific goal and targets and this goal focuses on to conserve and sustainably use the oceans, seas and marine resources for sustainable development [1], [2]. One of the type of marine resources includes seashells. Most shells comes from soft-bodied mollusc and the empty ones are the shell that is left behind by the animal when they died [3]–[5]. They are largely composed of calcium carbonate with a small amount of protein – usually no more than 2% [3], [5], [6]. Calcium carbonate on the other hand is one of the abrasive agent that is present in toothpastes. Abrasive agents are not only the fundamental in removing dental surface stains, they also improve tooth brushing efficiency [7]–[12].

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2. Materials and Methods

The main goal of it is to examine the scratch and depth analysis when seashell shell waste is used as the abrasive agent in the toothpaste. Due to the current pandemic situation, actual experiment are not able to be done due to restrictions. In this chapter, analysis from previous experiments will be discussed instead where similar experiments and lab analysis has been done using different types of seashells as alternative abrasive agent for toothpaste. The seashells used are clams, mussels, cockles and oysters shell waste where all of them contained high percentage of calcium carbonate.

2.1 Methods

The review study starts with the understanding of the composition of seashells and the ingredient in the toothpaste that caused abrasiveness. After the two points are connected, the designing of the review study is done to ensure the title relevancy. Further into the flow, findings and data are sorted according to categories and then the critical analysis and discussion were done.

2.2 Equations

2.2.1 Scratch Factor

Scratch factor indicates the number of filaments of the toothbrush that holds the abrasive particles and causes scratches under different brushing parameters. It is to determine whether each particle is trapped under each filaments to produces scratches and as the number of scratches represents the particles entanglement hence the formulation are as follows:

$$Scratch\ factor = \frac{Number\ of\ scratches}{Number\ of\ filaments} \qquad \text{Eq. 1}$$

The higher the percentage value of scratch factor efficiency, the better the material is as an alternative abrasive agent. It shows that the material is hard enough to be able to cause scratch on the acrylic plate and remove debris and stains.

2.2.2 Drag factor

Drag factor indicates how long the filament can hold the abrasive agent particles during the brushing motions to produce continuous scratch per strokes. The toothbrush test rig has a maximum stroke length of 20mm. Each scratch were measured and the longest scratch for every brushing load applied were tabulated in the table. The drag factor are calculated using the formula:

$$Drag\ factor = \frac{Scratch\ length}{Stroke\ length} \qquad \text{Eq. 2}$$

2.2.3 Wear rate analysis

Wear rate analysis is needed to estimate the wear of an actual tooth during brushing process in real life. It is needed in this thesis to not only study the effectiveness of the abrasive particles in the toothpaste but also to see whether it is safe to use or the opposite. The removal of the material from the test sample surface acts as the wear rate of the acrylic plate. The wear rate is calculated from the weight and volume of the acrylic plates.

Theoretical Calculation

The volume of the acrylic plate V_n were calculated as follows,

$$V_n = \frac{\pi}{4} d^2 l \qquad \text{Eq. 3}$$

Where,

d^2	=	scratch depth of the acrylic
l	=	length of the acrylic plate

The volume loss of acrylic plate after tooth brushing $V_{L,}$ is calculated using the equation below,

$$V_L = V_1 - V_2 \qquad \text{Eq. 4}$$

And thus the wear rate of the acrylic plate was calculated by volume, $WR_{v:}$

$$WR_v = \frac{(V_1 - V_2)(p)}{V_1} \qquad \text{Eq. 5}$$

$$WR_v = \frac{(V_L)(p)}{V_1} \qquad \text{Eq. 6}$$

Where,

V_1	=	Volume of acrylic plate before the tooth brushing process
V_2	=	volume of acrylic plate after the tooth brushing process
V_L	=	Volume loss of acrylic plate
p	=	Load applied in the tooth brushing process

3. Results and Discussion

In order to determine whether seashells can be a good substitute for abrasive agent in toothpaste, brushing test is required to be done. This brushing test includes having the sample seashells powder and diluted it glycerol to create a slurry texture as the toothpaste. The brushing test or scratch test was conducted to obtain the scratch factor and drag factor which will be discussed under the scratch analysis subtopic, scratch pattern and scratch depth of the sample toothpastes. After that, another brushing test were also conducted but on a stained surface (stain on acrylic surface using a permanent marker) in order to actually see the scrapping process of the abrasive agents.

3.1 Scratch Analysis of Seashell Abrasive Particles

Scratch analysis is done to determine the scratch factor and drag factor of the different material used in the toothpaste during the brushing test. The scratches were analyzed under an optic microscope to obtain the number and length of the scratches.

3.1.1 Scratch Factor

For the first analysis, only three types of seashell abrasive particle will be discussed which are the mussel, clam and oyster particles. The reason behind this is because three of these particles had undergo the same lab experiment under the same parameters, therefore the findings can be simplified in one table (Table 1) and graph (Figure 1).

Table 1: Interpolated Scratch Factor of Mussel, Clam and Oyster particles

Particle	Size	Speed	Cycle	Load	No of scratches	Scratch factor	%
Mussel	63	100	0.5	0.0	42	0.21	21
				0.5	58	0.29	29
				1.0	90	0.45	45
				1.5	110	0.55	55
				2.0	100	0.50	50
Clam	63	100	0.5	0.0	38	0.19	19
				0.5	54	0.27	27
				1.0	86	0.43	43
				1.5	94	0.47	47
				2.0	72	0.36	36
Oyster	63	100	0.5	0.0	93	0.47	47
				0.5	125.5	0.63	63
				1.0	158	0.79	79
				1.5	176	0.88	88
				2.0	160	0.80	80

The rows highlighted in yellow indicates the best or the highest scratch factor value for each material while row highlighted in green is the interpolated value that is manually calculated. The reason for the interpolation is because oyster particle is missing one parameter from the original data which is the 0.5N load. It is very important to note that this value is by no means accurate but is sufficient enough to fill in the missing parameters in order to create a better data. The reason why experimented value is better is because it is more accurate and in some cases data are not always linear and can be very random but according to these three different materials a pattern of data can be observed. For each and every one of the material, it can be seen that as the load increases, the scratch factor also increases until at 1.5N where it decreases in percentage after. Therefore, it is quite safe to estimate the missing values from the oyster missing parameter which is 0.5N by using the interpolation method as according to the pattern, it is still in the rising in value region. Figure 1 is the graph representation of the data from the previous Table 1.

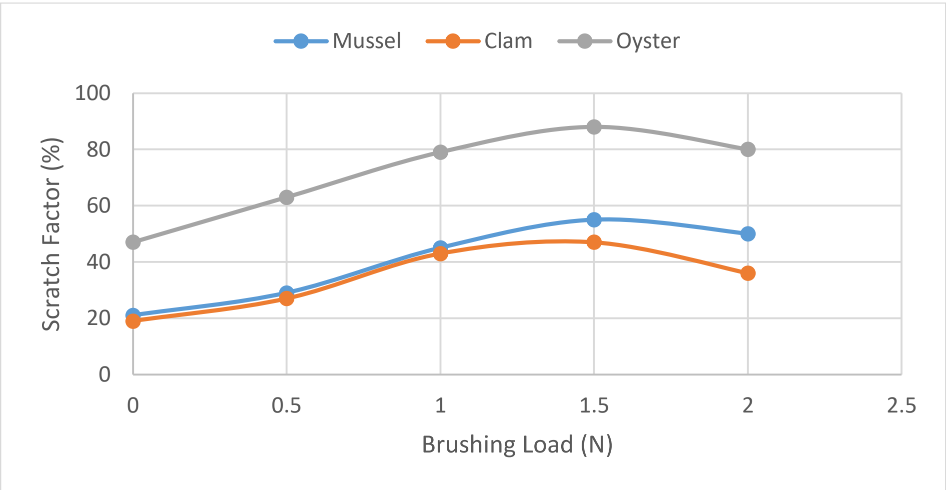

Figure 1: Scattered graph of mussel, clam and oyster scratch factor

As can be seen from the plotted graph, oyster shell slurry holds the highest scratch factor values compared to mussel and clam shell waste. It can be seen that the efficiency of scratch factor for all three types of material increases as the brushing load increases until 1.5N where all of the three graphs dropped. Load 1.5N can be called as the optimum load where it determines the maximum amount of load that the filaments can hold before they started to bend. Abrasive particles suspended in fluid approaches the filament and as they passed through the contact region between the tip of the filament and acrylic plate, the particles were trapped, therefore are able to create scratches. However, that is not the case if the filaments are bent because the particles are now then entrained at the end of the filaments and does not make contact with the acrylic plate – hence no scratches are made resulting in the decrease in value of the scratch factor.

Cockle shell waste were not discussed in previous discussion because it is experimented in a slightly different parameter compared to the other materials. The slight different however cannot be put together in the same table or graph. From the study, the same brushing test were done but with different parameters. First, the experiment started with constant load instead of having a range of loads to compare. With this constant load, it can now be determined whether the one with the best brushing cycle that produces the best scratch factor efficiency. Table and plot data graph below are the findings.

Table 2: Scratch Factor of Cockle particle

Particle	Size	Speed	Load	Cycle	No of Scratch	Scratch Factor	%
Cockle	63	100	2	0.5	85	0.425	42.5
				1	97	0.485	48.5
				20	189	0.945	94.5
				50	163	0.915	91.5

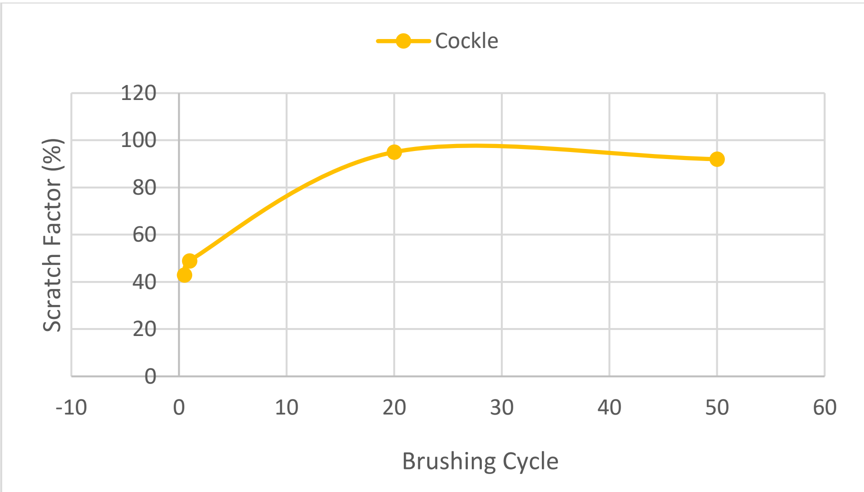

Figure 2: Scattered graph of cockle scratch factor

It can be found that with the constant 2N load, the result that produces the highest result is the 20 cycle parameter. The graph is very similar to the ones that have been discussed before however instead of increasing in load, this graph shows an increment as the cycle increases until it reached its optimum cycle value where it started to decrease right after. This findings is align with the observations of Lewis R. et al. [13], who discovered that after reaching the optimum brushing cycle value, the scratches created will decrease. Because the filament bended a little, it just could not make as many scratches as when it was not bended, it appears that the toothbrush filament was struggling to hold the particles in the contact region.

3.1.2 Drag Factor

Each scratch was measured and the longest scratch for every brushing load applied were tabulated in the table. For the drag factor analysis, all materials underwent the same parameters which is brushing test with constant brushing cycle of 0.5 cycle. Therefore, only one table of data will be discussed in this subtopic. The findings are as follows (Table 3):

Table 3: Interpolated drag factor data of mussel, clam, oyster and cockle shell waste

Particle	Size	Speed	Cycle	Load	Scratch length	Drag factor	%
Mussel	63	100	0.5	0.0	13.24	0.66	66
				0.5	14.34	0.72	72
				1.0	16.26	0.81	81
				1.5	17.36	0.87	87
				2.0	16.68	0.83	83
Clam	63	100	0.5	0.0	12.39	0.62	62
				0.5	13.29	0.66	66
				1.0	14.58	0.73	73
				1.5	15.35	0.77	77
				2.0	14.75	0.74	74
Oyster	63	100	0.5	0.0	12.17	0.61	61
				0.5	14.915	0.745	74.5
				1.0	17.66	0.88	88
				1.5	17.82	0.90	90
				2.0	15.64	0.78	78
Cockle	63	100	0.5	0.0	9.19	0.46	46
				0.5	9.84	0.49	49
				1.0	10.49	0.52	52
				1.5	11.39	0.56	56
				2.0	12.294	0.61	61
				2.5	10.74	0.54	54

Similar to previous table, the rows highlighted in yellow indicates the best brushing cycle value that has the highest efficiency of drag factor while the rows highlighted in green indicates the interpolated data that has been calculated manually. It can be seen that for each material, the pattern of the data is almost the same as scratch factor for all materials except for cockle shell and that will be further discussed in subsequent paragraph. Mussels, clams and oyster shell shows an increment in drag factor efficiency as the brushing load increases. However, at load 1.5N, all three materials show that they have reached their optimum load value and the graph for all three decreases after. This is mainly due to the fact that the filaments are bent and are no longer able to hold the particles at contact region as mention in previous subtopic. Generally, at higher loads the abrasive particles were dislodged as a result from the bended filament and thus long continuous strokes are not able to be made. It was thought that the particles were either moved to other filament tips or trapped between filaments during brushing motion. Either way, particles are not on the contact with the filament tip and acrylic plate and resulted in decreasing drag factor value.

However, as for cockle shells, the graph shows different result from the rest of the materials. One of the major reason behind that is because of the ununiformed data. For cockle shell, the brushing loads that were used are 0N, 1N, 1.5N, 2N and 2.5N – which 2.5N is not used in the other materials for tooth brushing test. As mentioned before, interpolation data are not accurate as some data are not always linear and can be very random at times. In this case, the data for cockle shell is missing the parameter at 1.5N – which is the optimum load value for mussel, clam and oyster shell. Because of the missing data, it can be only estimated using interpolation method and this can lead to errors like this. However, her data shows identical graph pattern as the rest of the materials. According to her data, the optimum value for cockle shell is at 2N and the value decreases as the load increases. This shows and explains the same concept as before where higher loads tend to dislodge the abrasive particles in the contact region as the filament started to bend. The abrasive particles are no longer in contact between the filament tip and the acrylic plate, therefore no or less scratching occurs. The optimum load from her data also almost correlates with the recommended brushing force mention in Carranza's Clinical Periodontology [79] which is between 1.4 to 2N.

3.2 Effect of Seashell Abrasiveness to Scratch Pattern

Results from scratch analysis shows that two of the most important factor that will help stain removal are the parameters brushing load and brushing cycle. It is important to understand the process of abrasive particles entrainment between the filaments during the tooth brushing process. Other than using numerical data as of scratch analysis, it is also important to see the pattern of the scratches for every parameter.

3.2.1 Brushing load effect to scratch pattern

From scratch factor analysis, it can be concluded that as the brush load increases, the number of scratches would also increase until they reach their optimum load value where they decrease in number of scratches after. These number of scratches technically shows the abrasion that is happening on the enamel. The higher the number of scratches, the better the parameter is in removing stains on the tooth. Every particle was experimented using different load values however, this ununiformed data will not affect the overall result at the end as what is more crucial is the trend of the scratches rather than just the numbers of parameter values as long as there are still within the recommended load value for tooth brushing.

- Mussel

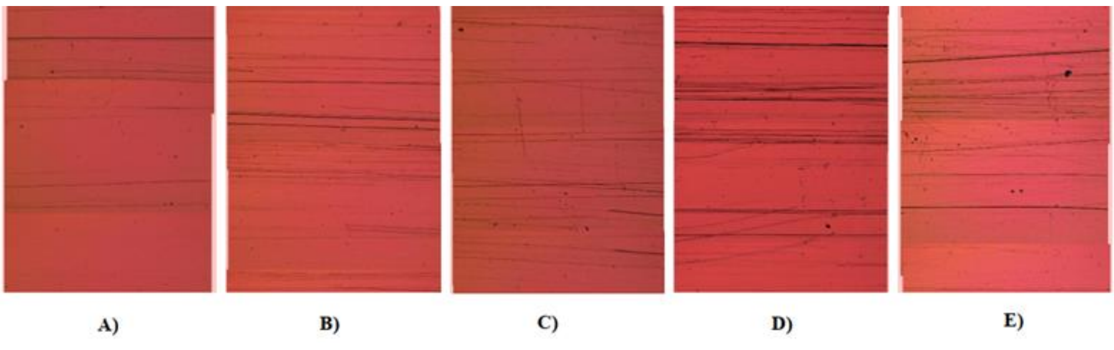

Figure 3: Mussel shell waste brushing load scratch pattern (A= 0N, B= 0.5N, C=1.0N, D=1.5N, E=2.0N)

- Clam

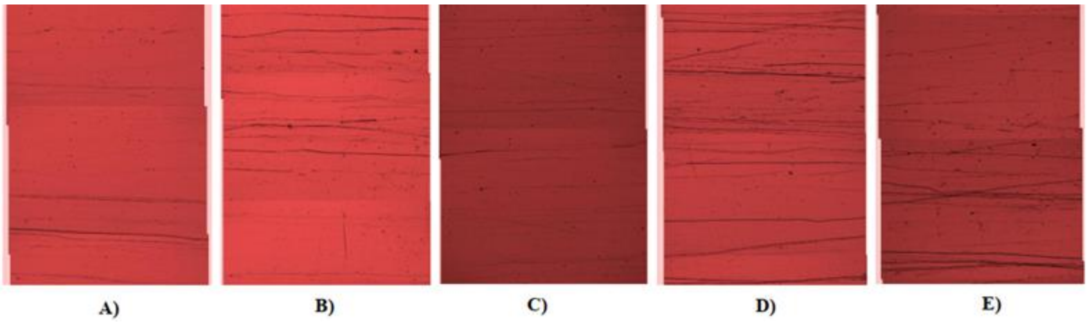

Figure 4: Clam shell waste brushing load scratch pattern (A= 0N, B= 0.5N, C=1.0N, D=1.5N, E=2.0N)

- Oyster

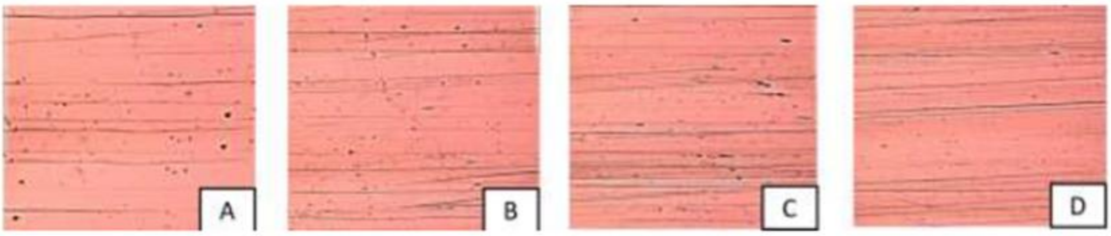

Figure 5: Oyster shell waste brushing load scratch pattern (A= 0N, B=1.0N, C=1.5N, D=2.0N)

- Cockle

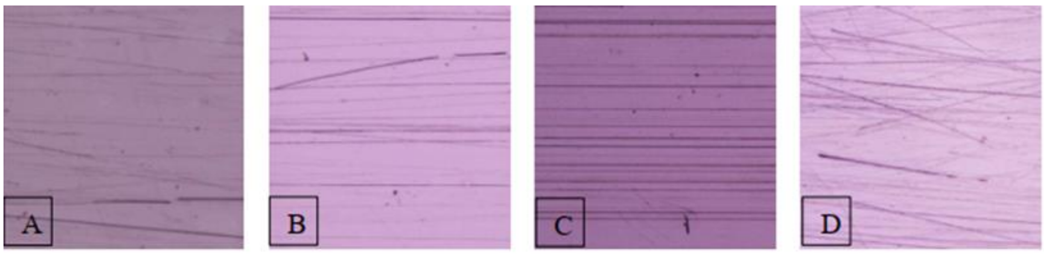

Figure 6: Cockle shell waste brushing load scratch pattern (A= 0N, B=1.0N, C=1.5N, D=2.0N)

According to the pictures above, we can see the trend in the scratch pattern which are similar to the trend that is from the scratch factor data. The trend started off as an increment in the number of scratches until they reached their optimum load value. As mentioned in scratch analysis subtopic, the reason behind this is simply because the filament bended. During the increment region (before optimum load value), the abrasive particles were clinging onto the tip of the filament and when the tip meets in contact with the acrylic plate, scratches were made. When the filament bended, the tip of the filament is no longer able to meet in contact with the acrylic plate and also making it harder for the particles to stay at contact region thus causing the decrement in scratch number. The increment itself happens when load is added. Basically, the applied load changes the geometry of the contact and the scratches are more profound (deeper) as the load increases.

3.2.2 Brushing cycle effect to scratch pattern

Similar to cockle shell scratch analysis where it can be concluded that as the brushing cycle increases, the number of scratches would also increase as well. These increment will continue until they reach their optimum cycle value and the number of scratches would decrease after.

- Mussel

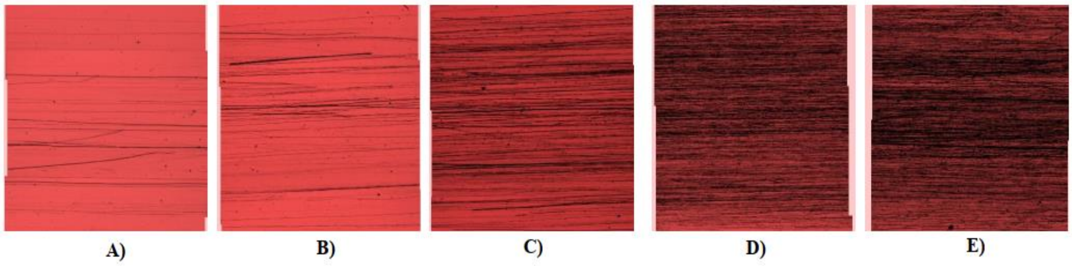

Figure 7: Mussel shell waste brushing cycle scratch pattern (A= 0.5cycle, B= 1cycle, C=5cycles, D=25cycles, E=50cycles)

- Clam

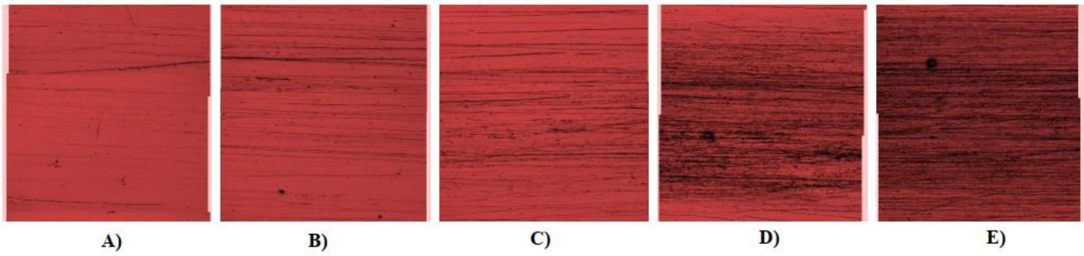

Figure 8: Clam shell waste brushing cycle scratch pattern (A= 0.5cycle, B= 1cycle, C=5cycles, D=25cycles, E=50cycles)

- Oyster

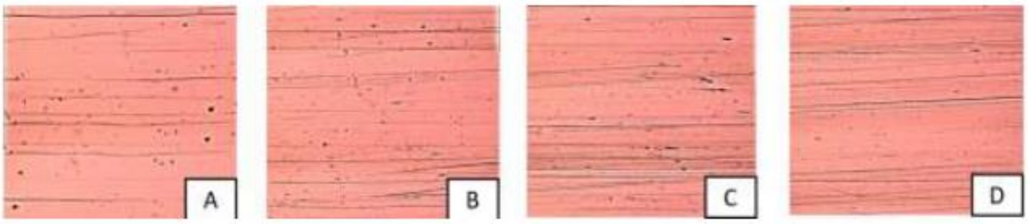

Figure 9: Oyster shell waste brushing cycle scratch pattern (A= 0.5cycle, B= 1cycle, C=10cycles, D=20cycles)

- Cockle

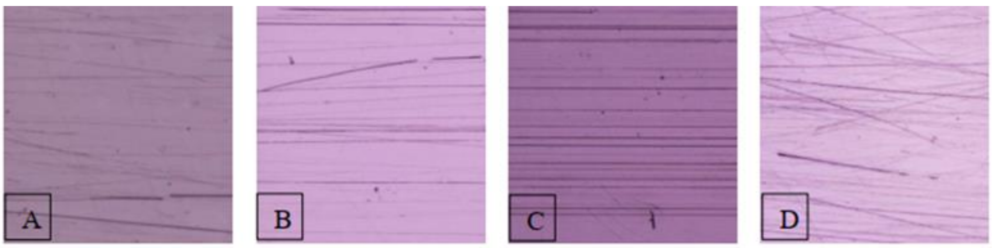

Figure 10: Cockle shell waste brushing cycle scratch pattern (A= 0.5cycle, B= 1cycle, C=10cycles, D=20cycles

As can be seen from all of the scratch patterns made by all materials in different parameters, a similar trend from the brushing load affect can be seen as well. With all of the materials, the number of scratches increases as the brushing cycle increases. The reason behind this is simply when the slurry is being drag back and forth for several times at the same spot, scratches will definitely occur therefore, the more cycle it undergoes the more (or deeper) scratches it creates. However, as it reaches a certain number of cycle, it reached its peak and the number of scratches can be seen decreasing right after. Similar to previous discussion, it can be said that the reason behind this fact is simply because the filament of the toothbrush bended, therefore there is no contact between the filament and the acrylic plate hence the abrasive particles have nothing to cling on to.

3.3 Depth of Scratch Analysis

Tooth abrasion is usually related to the most fundamental wear process of abrasive wear and erosive wear. In this subtopic, the depth of the scratches are studied to further analysed the effectiveness of the seashell particles as abrasive agents and whether or not they are efficient in cleaning the teeth or just causing more damage to the enamel instead. It is almost impossible to compare the results between all of the materials as the parameters used to examine their depth are different despite underwent the same experiment. However, general idea and conclusion can be made as the most of the differences are only the value of the parameters which most of them are still in the range of the same optimum value. Simplified data are tabulated in the Table 4.

Table 4: Simplified surface profile findings of mussel, clam, oyster and cockle shell waste under different parameters

Particle	Load	Cycle	Maximum depth
Mussel	1.5	50	0.1515
Clam	1.5	50	0.1306
Oyster	1.5	20	0.2200
Cockle	2.0	20	0.3720

Cockle shell particle has a different optimum load value compared to the rest of the seashell. It was also concluded that the reason behind that might be because of the insufficient of experimented parameters that has been done by the author itself. To put it simply, one of the reason why cockle shell might have different optimum load value is because the author did not have the data for the 1.5N load which happens to be the optimum load value for mussel, clam and oyster shell. Hence, it is thought that if the 1.5N load data exists, the result might be different. All of these results shows that all materials are capable of removing a tiny chunk of the article plate as a representation on removing actual stains on the teeth either it be bigger or smaller loads, higher or lower brushing cycles, it can be said that as long as the tooth brush is reciprocating and has 1.4N to 2N range of load, it is capable in removing the stains on the surface of the teeth.

3.4 Artificial stain removal

In order to further authenticate the conclusion and finding from previous subtopic, a validation test were conducted. Basically, a thin layer of permanent maker was applied on the surface of the acrylic plate to act as stain on an actual tooth. From the Table 5, the most general conclusion that can be made is that all material are efficient in removing tooth stain because they all exceed the thickness of the artificial stain or the permanent marker. Even though the difference in parameters might not give the best and accurate conclusion, but in general it can be said that all materials are able to remove the stain because the depth of scratch is deeper than the artificial stain thickness.

Table 5: Depth of scratch data of mussel, clam, oyster and cockle shell waste for artificial stain removal validation test.

Particle	Thickness of artificial stain	Load	Cycle	Depth of scratch
Mussel	0.1	1.5	50	0.1558
Clam	0.1	1.5	50	0.1425
Oyster	0.1	1.5	20	0.2370
Cockle	0.1	2	20	0.3930

3.5 Wear rate of seashells on acrylic plate

Wear rate can also be described as the volume loss per unit distance and is independent of load. It is important in this study to see whether the abrasive particles are not only efficient enough but also safe enough to be used in toothpaste.

Table 6: Wear rate of abrasive seashell particles on acrylic plate.

Particle	Load (N)	Depth of Scratch	Volume after tooth brushing (μm^3)	Volume Loss (µm)	Wear Rate (Nµm)
Mussel	1.5	0.1558	9.4233 x 10^{10}	1.5 x 10^7	2.3873 x 10^{-4}
Clam	1.5	0.1425	9.4234 x 10^{10}	1.4 x 10^7	2.2282 x 10^{-4}
Oyster	1.5	0.2370	9.4225 x 10^{10}	2.3 x 10^7	3.6606 x 10^{-4}
Cockle	2	0.393	9.4211 x 10^{10}	3.7 x 10^7	7.8516 x 10^{-4}

A study on wear rate analysis of seashells done in the past had stated that the wear rate increases as the load increases [14] which is almost similar to the data that is obtained in this thesis. Even though in this thesis, comparison between different loads are not made but from the ununiformed data the cockle shell shows almost more than a double of wear rate value compared to the rest of the materials because it has slightly higher load applied. Mathematically, it is assumed the other materials would have an increment in wear rate value also if they experience higher load pressure. As for the safety of the abrasiveness of the materials as abrasive agent, the volume loss of the acrylic plate does not exceed even half of the original volume of the acrylic plate. This shows that the materials used in the toothpaste as abrasive agent is hard enough to only scrap the thin layer of the acrylic surface without damaging the acrylic plate. In real life, it can be said that the abrasive particles in the toothpaste are only hard enough to scrap the stains and debris on the surface of the tooth without damaging the enamel which may cause problems to the teeth.

4. Conclusion

As conclusion, this thesis focuses on the sustainability development for seashells as alternative abrasive agent in toothpaste where one of the type of abrasive agent of toothpaste is calcium carbonate and seashells are made up of 95%-98% is calcium carbonate. From all of the test similar outcomes are found and that is the most crucial factor that effect the brushing test is the parameter brushing load and brushing cycle. It is found that the higher these two parameters are the higher number of (or deeper) the scratches will be until the filament started to bend. One of the biggest amendment that can be made is to have a uniform data with all experiments were done in the same parameters. This is to ensure that better discussion and justifications can be made without having to assume which may cause errors. Another suggestion that is worth for future researchers to consider is to have the wear rate compared to an actual RDA value. The RDA value is much more reliable and accurate to determine the safety of abrasive particles in toothpaste and are used by all of toothpaste companies worldwide.

Acknowledgement

The authors wish to thank to the Faculty of Mechanical and Manufacturing Engineering, Universiti Tun Hussein Onn Malaysia that has supported on the accomplishment of research activity.

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