Evaluation of the Effect of a Modified Version of Machinable Dental Wax for CAD-CAM Purposes

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Abstract
Background Even though laboratories generate a lot of amount of waste material, dental waste management has recently received a lot of attention. Proper waste management and efforts to improve it lead to cost savings. Machinable wax is often a reusable wax; the properties of the wax before and after recycling must be taken into account. **Objectives** of the present study are to evaluate the hardness and the melting flow of the new modified version of machinable dental wax for CAD-CAM purposes. **Materials and Methods** Mixing mineral and dental waxes in different ratios resultant: Type (I) with the following composition: melt machinable wax (60g), sticky wax (30g), paraffin wax (5g), and inlay wax (5g). While Type (II): melt machinable wax (55g), sticky wax (30g), paraffin wax (5g), and inlay wax (10g). The two experimental groups of Type (I) and Type (II) wax compared with one of the commercially available CAD-CAM wax (Dentify, Germany) as a control group. One-way ANOVA test (post hoc Games-Howell and LSD) was used for this study data analysis. **Results** After comparing the results, a significant difference in the surface hardness of study groups Type (I) and Type (II) was noticed compared to the control group ($P \leq 0.05$). However, there is a non-significant effect noticed for flow index property ($p > 0.05$). **Conclusions** The recycling of machinable wax block and reuse it as a dental wax ingredient show a superior surface hardness with a modifying of new version CAD-CAM wax. The incorporating of fresh material into recycled dental machinable wax enhanced the surface hardness and kept the melting flow index the same.

Keywords: CAM; milling; melt flow; wax; surface hardness.

Introduction
Dentistry has grown significantly throughout the last centuries. Various materials are included in dentistry for a wide range of clinical or laboratory procedures. Waxes play a major role in the final metal or ceramic restoration›s fabrication and success. The use of wax in dentistry dates back 200 years when beeswax was used to create dental impressions, (Craig and Powers, 2002; Emmott, 2011; Sheriff and Nittla, 2019). Dental waxes are used in a variety of dental procedures because they are inexpensive, non-toxic, lower melting range, and weak solids that can be easily molded and shaped. They›re used for both high-precision jobs and more straightforward activities in dentistry. Just a few pro-

cesses in restorative dentistry and patient-friendly technology are performed without the use of wax in one of its many forms, (Greig, 2012; Sulaiman, 2020). Waxes often have many characteristics that can be easily formed and molded, such as rubber, low melting, combustible and not toxic, flow, residual stresses, (Scheller-Sheridan, 2010; Von Fraunhofer, 2013; Sheriff and Nittla, 2019). Easy of recycling, (Taşçıoğlu and Akar, 2003). Flow is critical in all dental wax applications, and it is disadvantaged by residual stress effects, (Christensen, 1965), and thermal expansion, (Craig et al, 1965). The flow of dental wax can be changed by modifying composition, (Craig et al, 1966; Hatim et al, 2011; Powers and Wataha, 2014). However, there is no rigorous flow specification and also no attempt is made to describe these materials rheologically. Because of the difficulties in dealing with them, (McMillan and Darvell, 2000). On the other hand, the coefficient of thermal expansion of Inlay wax has a large CTE. It has a linear expansion of 0.7 percent with an increase in temperature of 20°C. Its thermal changes are greater than those of any other dental materials, (Phillips et al, 2013; Manappallil, 2015). In general, lower melting temperature waxes have greater ductility at any given temperature than higher melting temperature waxes, (Craig and Powers, 2002). The lower the flow rate at a given temperature, the harder the wax, (Anusavice et al, 2012). In dentistry, rapid prototyping (RP) is used for a variety of dental specialties. It has the benefits of simplicity, dependability, accuracy, improved visualization, and time savings, (Das et al, 2019). In consideration of this recent technical advancement, machinable wax has made significant strides in the field of dentistry. Milling or machinable wax can be shaped by milling or machining using CAD-CAM or dental drills. Machinable wax is an extremely hard wax with a high melting temperature that is formulated to deliver machining properties including high-resolution detail. One of the hard waxes with a high melting temperature is machinable wax, (Manappallil, 2015). Machinable wax contains 5-15 percent paraffin wax, 5-15 percent microcrystalline wax, and 5-10 percent ethylene/vinyl acetate copolymer. 40 to 50 percent by volume of a nonemulsifiable polyethylene wax with a melting point of substantially 220°F, 25-35 percent by volume of a non-emulsifiable polyethylene wax with a melting point of nearly 240°F. Paraffin was used to reduce the viscosity and melting point of the blocks, making them incredibly simple to process, (Cilindro, 1985). Within petroleum wax, paraffin wax is known as natural wax. It is primarily derived from petroleum›s high boiling point fractions, (Okorie et al, 2019). It is possible to improve the plasticity by raising the concentration of paraffin with a low melting point (50/52°C), which has a considerable effect on the flow of dental wax, (Zbigniew, 2019). Hassan et al. discovered that modifying dental wax improved its physical properties over commercial wax and the inclusion of paraffin wax improves wax melting range, (Hassan et al, 2014). Machinable wax has a major benefit over other materials in that it can be machined easily with little to no tool wear and may need no lubricant. In modern dentistry, machinable wax was chosen because of its non-abrasive properties, low environmental impact, and laboratory time savings. However, importing it is costly, and unused monoblocks are discarded after milling. The downside of this method is that it produces a significant amount of waste raw materials, which is considered uneconomic, (Sun and Zhang, 2012; Zaley, 2013), Despite some studies indicate that many dental materials may be non-reusable, waxes and metals are examples of these because of their properties change, rendering them unsuitable for future dental laboratory procedures, (Powers and Wataha, 2014). But, when the waste material is properly handled, leads to improved job quality for both professionals and the general public. Dental waste management is of significant social importance to society, (Fan and McGill, 1989). Several attempts have shown that approximately 80-90% of wax can be recycled without changing its properties using a simple laboratory technique for removing impurities, (Thopegowda et al, 2013; Arora et al, 2017). Thus, Biernacki et al, conclude that the wax pattern mixture obtained from the recycling of hard waxes, rather than fresh mixtures, could be used to perform accurate castings and reduce energy consumption in manufacturing high-quality investment patterns for general engineering applications and that the concept of larger recycling and treatment of wax should be considered (Biernacki et al, 2015). This also may support Ashby and Jones who previously proposed that the recycling of re-used materials may be a more effective energy-saving process (Ashby and Jones, 1995). As a result, the wax can be extracted, purified, and new wax made and recycled. This technique would increase income for dental schools and also help the low-income patients by lowering their care costs, (Thopegowda et al, 2013; Zaley, 2013). Except for Hatim et al in (2006), there were no serious attempts to manufacture new versions of wax locally in Iraq and at affordable prices (Hatim et al, 2006). Therefore, the present study designed to prepare a new wax for the CAD-CAM milling production method by reusing the waste-wax patches after the milling procedure with the addition of many mineral and dental waxes at a different percentage.

Materials and Methods

Pilot study

Initially, the milling wax [waste-wax patches from CAD-CAM milling procedure] measured for surface hardness and melting flow index. The 12th attempt was established to experiment with wax type and weight for study decision. The initial experimental study groups (n=3) were selected based on the control milling wax in terms of surface hardness as mechanical properties and melt flow index as rheological property.

Wax selection

According to the pilot study, four different dental wax materials were used namely a blank of CAD-CAM wax (Zotion™, China), sticky wax (Renfert, Germany), inlay wax (Renfert, Germany), paraffin wax (Middle Refineries Company/Dora Refinery/Iraq). Two study experimental groups of Type (I), and Type (II) were prepared with different ratios according to the following table (1).

Study sample grouping

For this study, a study sample of (70) cylinder specimens was prepared for surface hardness test (n=10), and (21) cylinder specimens for melt flow index (n=3).

Sample preparation

For the surface hardness and melting flow index, a silicon mould for the wax cylinder specimens was prepared and designed with a dimension of 12(± 0.1)mm× 13(± 0.1) mm in length and diameter respectively. To prepare the control group, the machinable White wax of D98.5*14mm (Dentify GmbH, Germany) milled into a cylinder shape using computer-aided design/computer-aided manufacturing (CAD-CAM), (imes-icore, Germany). While the study wax groups prepared by melting waste machinable blue wax D98*14mm (Zotion™, China) at high temperatures range between (115°C-186°C) on a refractory container on a Tefal pot over an electronic heater. A dental investment material was used as a thermal medium between the pot and the wax melt container. The temperature was measured using an external thermometer for keeping the wax›s temperature under control. On other hand, the other dental wax materials like sticky, inlay, and paraffin wax are melted using a digital wax melter device (Aicok, UK) and then poured into the silicone mould. For experimental study groups, the waste machinable wax melted firstly using the wax melt refractory container with the external digital thermocouple, then the sticky, inlay, and paraffin wax that melted using a digital melter device were added at a temperature of 185.5⁰C. The wax mixture was blended for 100 Sec using a handpiece with a fan bur. Then the wax was poured into the silicone mold and kept over the bench for 1h to solidify.

Testing procedure

In this study, the surface hardness test was performed by using the Shore-D durometer hardness device according to (ASTM D2240). The testing loads were applied equally to 50 N, and the wax specimen was located under the indenter area with a depressing time of measuring equal to 15 sec. The indenter of the digital Shore D device is 0.8 mm in diameter and a tapering cylinder of 1.6 mm. The three readings were obtained from the digital scale, (Cevik and Yildirim; Bicer, 2018). Each scale results in a value between (0 to 100) hardness numbers, with higher values indicating a harder material, (Gałuszka et al, 2017; Kajdas et al, 2017; Oleiwi; Hamad, 2018). While the melt flow index tester (XNR-400D) was used to measure the melt flow index of each group as an additional property alongside the surface hardness in terms of material›s viscosity and molecular weight for burn-out purposes, (Garg and Singh, 2016), as shown in figure (2).

Statistical methods

The study data were analyzed via One-way ANOVA followed by post-hoc tests; Games Howell and LSD at a confidence level of 95% and a significant P-value of ($p \leq 0.05$).

Results

The data were statistically analyzed by comparing the results of surface hardness and melt flow index properties. Tables (2) and (3), and Figures (3) and (4) show the results of surface hardness and melting flow index of the studied groups. Generally, a significant increase in the surface hardness was noticed in the experimental studied groups of Type (I) and Type (II) than that of machinable CAD-CAM wax (Germany) as a control group, ($p \leq 0.05$). Yet, Type (I) experimental wax showed the same surface hardness value as that of Type (II) ($p > 0.05$). On the other hand, the Type (I) and Type (II) experimental wax show a statistically significant decrease in melt flow index than that of the machinable CAD-CAM wax (Germany), ($p \leq 0.05$).

Table (1): The percentage in weight of the studied wax.

Groups	Wax Ratio			
	CAD-CAM Wax Wt. % (g)	Sticky Wax Wt. % (g)	Hard Inlay Wax Wt. % (g)	Paraffin Wax Wt. % (g)
Control Group	100 (Germany)	0	0	0
Type (I)	60 (China)	30	5	5
Type (II)	55 (China)	30	10	5

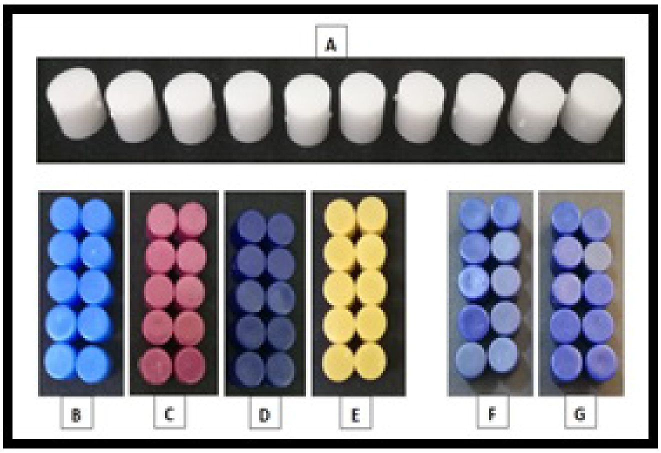

Figure (1): Study samples groups, A: Machinable wax (Germany); B: Melted machinable wax (China); C: Melted sticky wax; D: Melted inlay wax; E: Melted paraffin wax; F: Experimental Type (I) wax; and G: Experimental Type (II) wax.

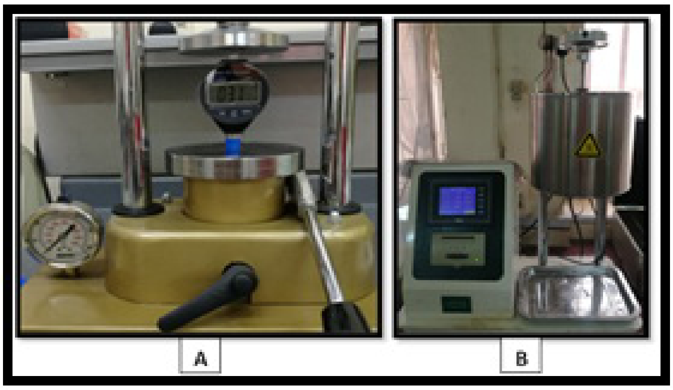

Figure (2): A: Surface hardness device (Shore D); and B: Melt flow index tester device.

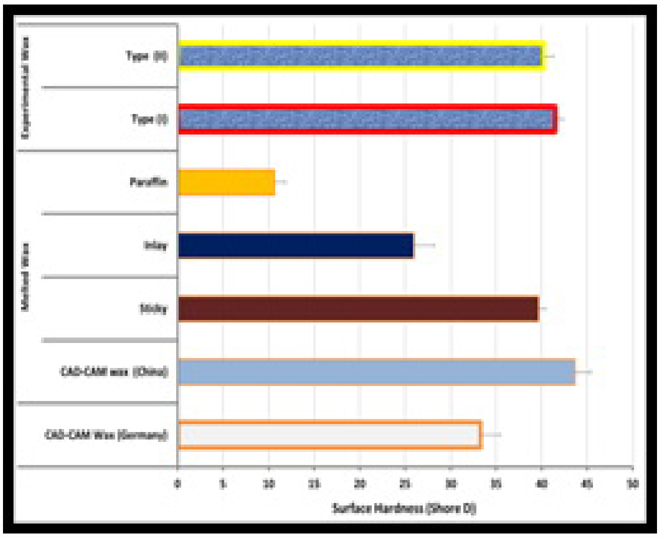

Figure (3): Bar chart showing the surface hardness means distribution of the studied wax.

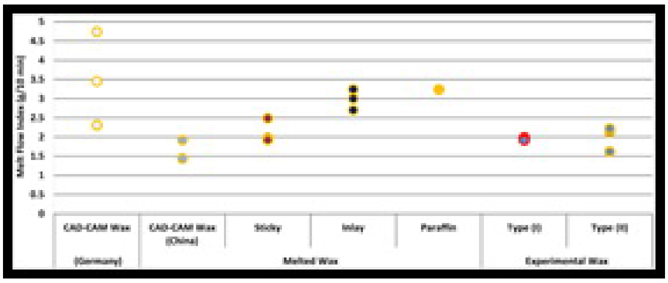

Figure (4): Diagram showing the melt flow index means distribution of the studied wax.

Table (2): ANOVA test (post hoc Games-Howell) showing the surface hardness of the studied wax.

Wax Groups		Mean Difference	*P*-value	Sig.
CAD-CAM (Germany)	CAD-CAM Wax-Melt (China)	-10.3667*	.000	S
	Melt (Sticky)	-6.4000*	.000	S
	Melt (Inlay)	7.3159*	.000	S
	Melt (Paraffin)	22.6000*	.000	S
	Experimental - Type (I)	-8.2333*	.000	S
	Experimental - Type (II)	-6.9833*	.000	S
CAD-CAM Melt (China)	Melt (Sticky)	12.8300*	.000	S
	Melt (Inlay)	26.5459*	.000	S
	Melt (Paraffin)	41.8300*	.000	S
	Experimental - Type (I)	10.9967*	.000	S
	Experimental - Type (II)	12.2467*	.000	S
Melt (Sticky)	Melt (Inlay)	13.7159*	.000	S
	Melt (Paraffin)	29.0000*	.000	S
	Experimental - Type (I)	-1.8333*	.003	S
	Experimental - Type (II)	-.5833	.906	NS
Melt (Inlay)	Melt (Paraffin)	15.2841*	.000	S
	Experimental - Type (I)	-15.5492*	.000	S
	Experimental - Type (II)	-14.2992*	.000	S
Melt (Paraffin)	Experimental - Type (I)	-30.8333*	.000	S
	Experimental - Type (II)	-29.5833*	.000	S
Experimental - Type (I)	Experimental - Type (II)	1.2500	.091	NS

Table (3): ANOVA test (post hoc LSD) showing the melt flow index of the study wax.

Wax Groups		Mean Difference	*P*-value	Sig.
CAD-CAM (Germany)	CAD-CAM Wax-Melt (China)	1.9000*	.000	S
	Melt (Sticky)	1.3700*	.003	S
	Melt (Inlay)	.5200	.205	NS
	Melt (Paraffin)	.2600	.520	NS
	Experimental - Type (I)	1.5367*	.001	S
	Experimental - Type (II)	1.5100*	.001	S
CAD-CAM Melt (China)	Melt (Sticky)	-.5300	.197	NS
	Melt (Inlay)	-1.3800*	.002	S
	Melt (Paraffin)	-1.6400*	.001	S
	Experimental - Type (I)	-.3633	.371	NS
	Experimental - Type (II)	-.3900	.337	NS
Melt (Sticky)	Melt (Inlay)	-.8500*	.045	S
	Melt (Paraffin)	-1.1100*	.011	S
	Experimental - Type (I)	.1667	.679	NS
	Experimental - Type (II)	.1400	.728	NS
Melt (Inlay)	Melt (Paraffin)	-.2600	.520	NS
	Experimental - Type (I)	1.0167*	.019	S
	Experimental - Type (II)	.9900*	.021	S
Melt (Paraffin)	Experimental - Type (I)	1.2767*	.004	S
	Experimental - Type (II)	1.2500*	.005	S
Experimental - Type (I)	Experimental - Type (II)	-.0267	.947	NS

Discussion

Several researchers have been recommended the reuse and recycling of different dental waxes for additional laboratory procedures. Yet, the high import cost of some dental waxes for CAD-CAM production methods may consequently influence the laboratory work environment. The shortage of some dental resources such as machinable wax seems to affect the dental market as well as further studies of some educational institutions. There is limited information regarding the recycling of dental waxes in terms of produce new machinable wax for CAD-CAM purposes. Therefore, this study designed to evaluate the surface hardness of the new machinable wax alongside flew melt index for CAD-CAM purposes. Generally, the new machinable wax created in this study shows a high surface hardness than one of the most commonly used commercially hard CAD-CAM wax disks (Dentify GmbH, Germany). The mixing of different dental waxes in terms of recycling the waste patches of machinable blue disk wax (Zotion™, China), sticky, and inlay wax (Renfert, Germany) in addition to paraffin as an Iraqi local mineral wax revealed a huge benefit in the creation of new products with a superior mechanical property like surface hardness. The China-machinable wax is harder than that of the other available wax of different origins lead to a long time-consuming milling process, as well as, some wax burs may undergo fatigue and fracture during the milling process. Type (I) and Type (II) experimental machinable wax showed a significant increase in the surface hardness comparing to one of the commercially available wax blanks. This could be related to the addition of a high percentage by weight of hard China-machinable wax of 60g and 30g of sticky wax. These findings may agree with a few studies that stated that the recycling of dental waxes may improve its properties by the addition of refreshing materials, (Thopegowda et al, 2013; Biernacki et al, 2015). On the other hand, the melt flow index of Type (I) and Type (II) experimented with wax indicates a significant decrease in mean value than the commercially used CAD-CAM wax (Dentify, Germany). This may be related to the inclusion of paraffin wax at a low flow melt point. This may in agreement with a study by Hassan et al, (2014) and Zbigniew, (2019). They conducted that the addition of paraffin wax could consider as an effect on the flow of dental wax, (Hassan et al, 2014; Zbigniew, 2019). Since the wax pattern formed after machining is invested and cast like regular casting waxes, the melt flow could play an important role in the process of wax extraction and burnout procedures. This may help time-consuming alongside the accuracy of the final restoration. This study was limited to surface hardness and flow index properties; however, many additional mechanical and physical properties such as microhardness and the dimensional accuracy of the wax pattern and final restoration were needed for further investigation.

Conclusions

This study concluded that the addition of different melted dental waxes to recycled machinable wax could produce a new hard wax for CAD-CAM purposes. The addition of the paraffin wax to the wax mixture lowered the melt flow range which provides one of the recommended factors in using castable waxes. To sum up, Type (I) and Type (II) machinable waxes that were created in this study should consider as one of the alternative options for limited commercially available wax blanks for milling systems.

Conflict of interest

We are the authors (Baidaa Abd Allah Ahmed, and Assist. Prof. Dr. Saja Ali Muhsin) state that the submitted manuscript for this paper is original. It has not been published previously, and it's part of the MSc. dissertation and is not under consideration for publication elsewhere, and that the final version has been seen and approved by all authors.

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