International Journal of Science and Research (IJSR)
ISSN: 2319-7064
SJIF (2019): 7.583

Temperature Related Physical Changes of Different Materials for Fabrication of Patterns for Casting from Dental Alloys

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Abstract: ***Introduction:*** *In contemporary dentistry there are a variety of materials which are used for fabrication of patterns that are invested and used as a pattern of the final restoration. Despite the ceaseless introduction of new materials, there is still less information about their physical changes during the process of thermal elimination.* ***Materials and Methods:*** *Four identical samples are prepared from the materials as follows: Pattern resin LC® (GC™), C-cast® (KaVo™ Dental), CAD/CAM wax (Yeti Dental™) and Castable Resin® FLCABL02 (Formlabs™). The samples are heated in furnace staring from 25°C to 1050°C and their main temperature related physical and volumetric changes are examined at every rise of temperature by 50°C.* ***Results:*** *When the CAD/CAM wax is heated, it starts melting before any visible volumetric changes of the sample are presented. The rest of the examined materials, as predominantly resin-based materials, start expanding at a specific temperature and after a further temperature rising, they start melting and burning afterwards or just burning rapidly.* ***Conclusion:*** *The main protocols of investing and casting should be modified in accordance to the thermal related physical and volumetric characteristics of the materials used for pattern fabrication.*

Keywords: prosthetic dentistry, dental materials, 3D-printing, temperature related changes, pattern fabrication

1. Introduction

There are two basic approaches for fabrication of fixed partial dentures.[11] One of them uses direct milling or printing of the restoration itself directly from the desired material. The second one utilizes fabrication of pattern that should be invested and replaced by dental alloys or pressed ceramics.[3, 8, 9] In contemporary dentistry there are vast number of materials that are used for fabrication of patterns that are invested and used as a pattern of the final restoration.[6]

The most commonly used material for pattern fabrication is wax. Usually it is a mixture of paraffine (40%-60%), gum dammar, carnauba, candelilla, ceresin and also auxiliary components (such as coloring agents or odour modifying agents).[1] Consequently, the physical characteristics of the wax mixture depend on its composition. The mechanical behavior is therefore temperature sensitive, depending on composition and number of phases.[1, 2, 10] Therefore, the waxes can be classified by their application as pattern waxes (inlay, casting, baseplate types), processing waxes (boxing, utility and sticky wax) and impression waxes.[1] Depend on its composition every type of wax has its specific characteristics that makes them very convenient to work with. Inlay waxes are those that are used for patterns fabrication. They are divided into 2 groups: type 1 – medium wax that is used in direct techniques and type 2 – soft wax - used in the indirect techniques. The melting range of these waxes is between 54°C and 60°C.[1] They all shouldn't leave a solid residue more than 0, 1% of the original specimen's weight.[1] There can be carved easily without fragmenting into flakes and allows making a smooth and shiny surface. All of these properties makes the inlay the most commonly used material for pattern fabrication.

There are also some issues according to their mechanical properties. They can flow under mechanical interaction while are slightly heated or even at room temperature. The patterns made of inlay wax can be easily deformed while they are removed from the working cast which creates another issue in accordance to their application. Another specific characteristic is their elastic memory.[1, 2, 10]

For that reason a new approach in wax processing is accepted. The wax is milled by a CAD/CAM machine. This approach reduces significantly the possibility of deformation, but the flowing is still remain as an issue.

In order to ensure a resistance of deformation to patterns a special acrylic resins for pattern fabrication are involved in practice. Gradually, acrylic resins start taking the place of the wax in daily dental technician's work. In comparison to the waxes they have better mechanical properties and are much more resistant to any thermal interactions by having a higher melting range. They are firm and stiff materials which allow fabrication of denture without significant deformations and acceptable accuracy.[2, 3] Because of their excessive expansion during the burning out process, their rigid structure and the obvious risk of mold fracture they are preferably used for a denture's base structure, which is covered and finished using wax.

Within the past couple of years with the development of the 3D printing a lot of new materials are introduced for that purpose.[4, 5] The majority of them are also resin based, but the production technology gives more option in dentures design. As a resin based the material is stiff and firm against any mechanical interactions and allows fabrication of patters with great accuracy and dimensional stability.[2, 12, 13] Together with the thermal expansion the main problem with some of the resin based materials for pattern fabrication is the direct sublimation, which can cause a mold fracture due to excessive gas pressure.[14, 15] Otherwise this approach in pattern fabrication and also the milling process of resin patterns reduce the wax usage and all of its disadvantages, besides they allow almost the same freedom and accuracy in production process.[7]

Despite a wider range of materials for pattern fabrication is available, there is still less information in the literature about the physical changes that these materials undergo in the stages of their thermal elimination in the heating oven.

2. Materials and Methods

For the purpose of the study four identical objects were prepared from the following materials.

A silicon mold with the shape of cylinder with base of 2 centimeters in diameter and a height of 2 centimeters was used to be filled with a **Pattern resin LC**® (GC™), and was left to cure.

The corresponding STL-file for the same size cylinder was used to get two other cylinders, milled from **C-cast**® (KaVo™ Dental), and **CAD/CAM wax** (Yeti Dental™).

The fourth identical cylinder was 3D printed by SLP technology from **Castable Resin**® **FLCABL02** (Formlabs™) as a solid object. And prior to heating was post cured at 60 °C for 240 min in Formcure® (Formlabs™)(**Fig.1**)

Figure 1: The examined samples are shown, from left to right as follows: CAD/CAM wax (Yeti Dental™), C-cast® (KaVo Dental™), Pattern resin LC® (GC™), and Castable Resin® (Formlabs™)

A pot from investment material Sherafina® Rapid (SHERA™) was poured and the objects were aligned into it and were inserted into the heating furnace for casting. The temperature rate is as shown on **Figure2.**

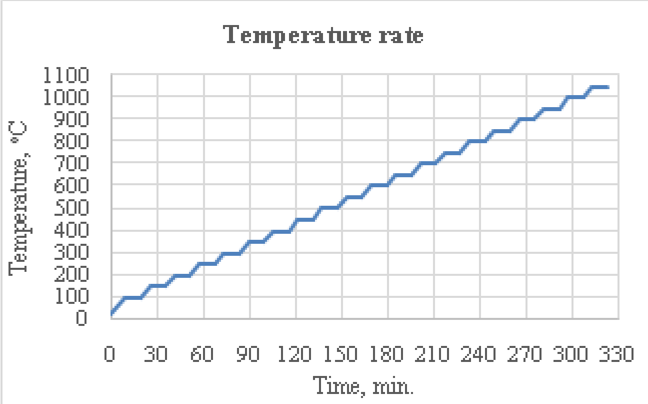

Figure2: Temperature/time chart

According to the temperature rate the pot is inserted at 25℃ and the temperature is raised to 100℃, then a 10 min. holding is presented. After that the temperature is raised to 150℃ and hold for 10 min again. The same pattern is repeated till 1050℃ is reached.

A comparison of the main temperature related physical and volumetric changes of the samples are made during different stages of the experiment.

3. Results

At temperature of 100°C almost all of the samples don't show any significant changes, except slight changes in the CAD/CAM wax specimen. Its edges start looking round and the surface has a mat texture. **Fig.3**

Figure 3: The four samples at temperature of 100℃.

At the temperature of 150°C any changes are absent in comparison to the 100℃. The physical condition, structure, color, texture of all the samples are unchanged, except the CAD/CAM wax specimen, which starts changing at the previous examined temperature level. **Fig.4**

Figure 4: No changes at 150℃ in comparison to 100℃.

At 200°C the CAD/CAM wax sample starts melting. The Pattern Resin LS™ (GC™) starts its temperature expansion. The upper surface of the sample made of Pattern resin LS™ starts bending and expanding. It is apparent that the diameter of the upper base of the cylindrical specimen is bigger than the lower one, which is result of the temperature difference between the pot and the air inside the furnace. When the C-cast® resin and CAD/CAM wax are inspected, there aren't any visible changes available.

Figure 5 - A shows the changes to the specimens at the moment when 200°C is reached and **Figure 5 – B** shows changes after the 10 minutes holding at the same temperature. After the 10 minutes holding, the CAD/CAM wax sample is already melted and starts boiling. The Pattern resin LS® continues its expansion. According to the pattern made of C-cast® and Castable Resin®, no any changes are visible.

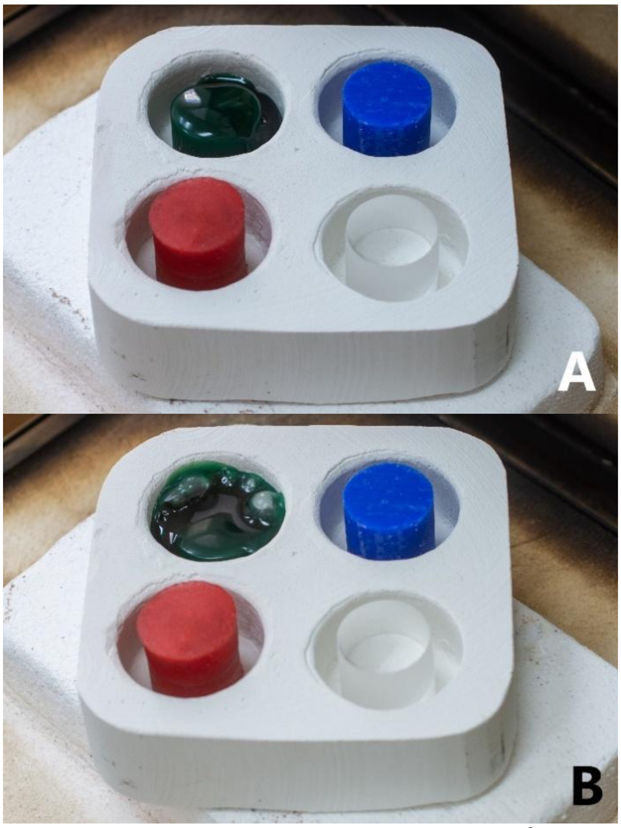

Figure 5: Structural changes of the samples at 200°C, before (Fig. 5 - A) and after (Fig.5 - B) the 10 minutes holding

At the temperature of 250°C the wax's pattern is still boiling. The expansion of the sample made of Pattern resin LS™ become significant and more evident. When inspecting the Castable Resin® sample the first visible signs of expansion are visible. A tiny fissure is presented over the base of the Castable Resin® cylinder, which is clear evidence for thermal expansion of the detail. It is apparent that fissures are parallel to the direction of the different layers. As of the possible reason for this phenomenon may be the lower energetic content of this space between the layers, due to presence of many free ends of the polymer chains between the printed layers. There aren't any visible changes to C-cast® pattern, in contrast to the rest of the specimens. **Fig.6 – A**

At the end of the 10 minutes holding Pattern resin LS™ sample start bending around its altitude, while its base looks bulkier and more rounded. At this level some other changes in Castable Resin® pattern become visible, it becomes a little darker in color and the count of the fissure is increased. The C-cast® shows still no changes. **Fig.6 – B**

Figure 6: Structural changes of the samples at 250°C, before (A) and after (B) the 10 minutes holding.

There aren't any significant changes between 250℃ and 300℃, so a picture of the samples at the temperature of 300°Cafter the hold is attached. **Fig. 7.** It is apparent that a small part of the CAD/CAM wax sample is evaporated. The Pattern resin LS™ sample almost twice its volume and become porous because of the excessive expansion. Due to coloring agent burning out, Castable Resin® sample becomes more and more dark and it still hasn't any significant volumetric changes. It is interesting to note that even at this temperature level there aren't any visible physical changes in

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C-cast® pattern.

Figure 7: Structural changes of the samples at 300°C after the 10 minutes holding.

At 350°C the described Castable Resin® specimen's signs of expansion become more and more evident. The C-cast pattern becomes porous, without showing any visible volumetric changes that probably can be noticed by any additional inspection. A superficially melting of the Pattern resin LS™ is visible. At the same time an initial carbonization of single components the CAD/CAM wax sample is visible like a blackpeel. **Fig. 8.**

Figure 8: Structural changes of the observed samples at 350°C, before (A) and after (B) the 10 minutes holding.

The described changes at 350°C are also manifested at 400°C, but more clearly. The CAD/CAM wax specimen continues its carbonization. The Pattern resin LS™ is melted and it starts boiling, some components of the resin are carbonized at the same time (the black zones of the Pattern resin LS™ sample's nest). C-cast® pattern has a reduced volume; it starts to lose its structure. The expansion of the Castable Resin® pattern is apparent, and its surface becomes shiny, because of the melting of the auxiliary components of the resin. **Fig. 9.**

Figure 9: Structural changes of the observed samples at 400°C.

Between 450°C and 550°C the rapid burning process is apparent. As a result, the C-cast® and Pattern resin LS™ samples show almost lack of residual ash remnants, in contrast to them the CAD/CAM wax and Castable Resin® samples, which leaves a residuum. **Fig.10 and Fig. 11.**

Figure 10: Structural changes of the observed samples at 450°C.

Figure 11: Structural changes of the samples at 550°C.

The observation of CAD/CAM wax and Castable Resin's® samples at 600°C shows small amount of ash remnants which are illustrated at **Fig. 12.**

Figure 12: Structural changes of the observed samples at 600°C.

Between 600°C and 1050°C there aren't any major changes, except the reduction of the ash remnants that are left by the wax and Castable Resin® samples. Figure 13 shows that reduction.

Figure 13: Residual ash remnants amount reduction at 1050°C.

4. Discussion

The differences of the physical changes of the observed materials in the course of the thermal elimination of the pattern are strictly related to their chemical structure.

If we observe the CAD/CAM wax sample, it is obvious that it melts around 200°C without any major expansion of the solid state, which prevents the mold form crack. It has the properties to be very good material for patterns fabrication, which is easy to work with. Despite all of these advantages, it has one major disadvantage, as a wax it has the ability to flow under prolonged mechanical interaction or due to temperature rising. This is a factor that may cause any kind of deformation of the patterns. For that reason, fabricated patterns should be kept away from any additional mechanical interactions or temperature changes and should be invested as fast as possible, as a prevention of any deformation of patterns.

When Pattern resin LS® sample is observed an excessive thermal expansion during burning out process is obvious. This may cause a mold fractures, as a result of the rising pressure against the mold walls. As a prevention of that the producer recommends a wax coverage of the outer pattern's walls to be made and investment material with higher strength to be used. Otherwise it is firm and stiff material which allow fabrication of denture without significant deformations and acceptable accuracy.

If the C-cast® is examined it is apparent that it has physical properties which are almost identical to the Pattern resin LS®. The main component of both materials is methyl methacrylate, both of them are firm and stiff materials and don't leave any residuals after burning out. Along with that, the C-cast® material has less thermal expansion and changes in its structure are visible at a higher temperature. These characteristics determine the material as suitable for fabrication of patterns which are not susceptible to any physical interactions and are firm and stable. Unfortunately, there isn't much information about the physical properties of this material at the scientific literature.

The Castable Resin® is a resin-based material that is produced by Formlabs™ for their SLP 3D-printers. When the material is heated it starts to sublimate and keeps its solid state for a long period, as a result a massive thermal expansion is available. This may cause mold fractures, due to thermal expansion of the solid structure on one hand, and on the other hand as a result of massive gas pressure against mold walls. Otherwise the material is stiff and firm against any mechanical interactions and also allows fabrication of patters with great accuracy and dimensional stability.

All of the observed materials have advantages and also disadvantages. In order to gain a cast with good qualities some modifications of the production process need to be made, according to specific physical properties of the materials.

5. Conclusion

3D printing of patterns is very convenient method, but there are some features like thermal expansion rate, volumetric changes, and ash remnants that have to be considered, when this approach is chosen. The physical thermal related behavior could cause a great impact on laboratory protocol. Depending on their thermal related physical and volumetric "behavior" it is mandatory, that some of the main parameters on the investing and casting protocols should be altered, in order to be consistent with their thermal related changes.

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