

**SETTING EXPANSION CHARACTERISTICS OF THREE PHOSPHATE-
BONDED INVESTMENT MATERIALS USED WITH HIGH FUSING HIGH-
NOBLE ALLOYS, COBALT-CHROME ALLOYS AND HEAT-PRESSED
LITHIUM DISILICATE CERAMICS.**

A Thesis

by

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Submitted to the Office of Graduate and Professional Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

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May 2017

Major Subject: Oral Biology

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ABSTRACT

The purpose of this study was to investigate the setting expansion characteristics of three commercially available phosphate bonded investment materials for casting high fusing alloys and heat pressed lithium disilicate. The experimental groups in this study were P90 (Powercast 90% Special Liquid for Cobalt-Chrome alloys), P60 (Powercast 60% Special Liquid for High Noble Gold alloys), FF75 (FastFire 15 75% Special Liquid for Cobalt-Chrome alloys), FF50 (FastFire 15 50% Special Liquid for High Noble Gold alloys), and PVS (PressVest Speed 60% Special Liquid for Lithium Disilicate Veneers, Partial Crowns and Single Crowns). Twenty specimens per group were poured in a trough that conformed to ADA Specification No. 2 for the measurement of the linear setting expansion of gypsum bonded investments. Measurements of the setting expansion were taken at 2, 4, 6, 8, 12, and 24 hours after mixing.

A one sample T-Test revealed that the setting expansion measured for all of the groups was statistically significant and that all of the groups exhibited statistically significant differences in setting expansion at the manufacturer's recommended burn-out time from the setting expansion reported by the manufacturer ($P \leq 0.01$).

P90, P60, FF50 and PVS showed less expansion than is required in order to fully compensate for solidification shrinkage during the casting procedures. FF75 was the only group that managed to fully compensate for the solidification shrinkage of the alloy it is intended for ($P \leq 0.01$).

The delayed burn-out times evaluated in this study resulted in significantly different setting expansion for PVS. A statistically significant difference was detected after 4 hours. The dimension of the PVS specimens did not change significantly after 4 hours. No such difference in setting expansion at delayed burn-out times could be detected for P90, P60, FF75 & FF50 ($P \leq 0.01$).

Within the limitations of this study, the setting expansion of the phosphate bonded investment materials tested could not fully compensate for the solidification shrinkage of the alloys except for FF75. Delayed burn-out times resulted in significantly different setting expansion for PVS. Significant differences at delayed burn-out times could not be detected for the rest of the groups.

CONTRIBUTORS AND FUNDING SOURCES

This study was supported by a thesis committee consisting of Dr. William W. Nagy, Dr. Elias Kontogiorgos, Dr. John T. Goodman from the Department of Restorative Sciences and Dr. David Murchison from the Department of Diagnostic Sciences of Texas A&M University College of Dentistry.

Statistical analysis of the research data was conducted in part by Dr. Elias Kontogiorgos.

All other work conducted for the thesis was completed by the resident independently.

Research funds were provided by the Office of Research and Graduate Studies of Texas A&M University College of Dentistry.

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1. INTRODUCTION AND LITERATURE REVIEW

The dimensional behavior of dental investment materials has always been an area of interest for researchers of the properties of dental materials. Different types of investment materials have been formulated in order to meet the evolving requirements of the process. Yet, the rationale for all of them has been the same; the investment material has to be a refractory material that can withstand high casting temperatures and a material that expands in order to counteract the solidification contraction of casting alloys or ceramic materials.

In 2011, Christensen [1] reported that the percentage of metal, metal-ceramic, and all-ceramic restorations fabricated at a major US dental lab changed significantly from 1997 to 2010. In 1997, seventy two percent of indirect restorations fabricated were metal-ceramic restorations, 12% were metal and 16% were all-ceramic and resin based composite. In 2010, the percentage of metal-ceramic restorations dropped to 45%, the percentage of metal restorations dropped to 6% and the percentage of all ceramic restorations increased to 50%. Furthermore, due to the increased prices of gold and silver since 2010, it is safe to expect a rise in the usage of base metal alloys for the fabrication of metal-ceramic restorations. Therefore, with regard to the study of the properties of investment materials, the types of investments that are used in the casting of high noble porcelain fused to metal restorations, the casting of cobalt-chrome alloys for removable partial denture frameworks and the investments used in heat pressing of ceramic materials like lithium disilicate glass ceramics are of interest.

Different investment types are indicated depending on the melting range of the alloy or ceramic material used. Gypsum-based materials (Type I & II) have been traditionally used to cast Type 3 gold alloy inlays, onlays & crowns. Phosphate-bonded investments were created to be used with metal-ceramic restoration alloys that require higher casting temperatures, and also for base metal alloys and pressable ceramics. In 1998 Takahashi [2] developed a new gypsum bonded investment suitable for casting high fusing alloys used in metal ceramic technology. This investment material was composed of gypsum as a binder and alumina as a refractory material. Ethyl silicate-bonded investments are used with cobalt-based and nickel-based alloys for the casting of removable partial denture frameworks. There have been attempts to cast commercially pure titanium and titanium alloys without major commercial application due to the highly sensitive casting technique with special investments and a controlled atmosphere [3]. The investment materials that are currently used for the majority of restorations belong to the category of the phosphate-bonded investments.

When evaluating the expansion properties of a dental investment material one has to determine the linear percentage of solidification contraction of the alloy or ceramic material, since the investment is supposed to compensate for that by providing a corresponding percentage of expansion. The linear solidification shrinkage of casting alloys has been calculated to be 1.56% for Type 1 gold alloys, 1.37% for Type 2 gold alloys, 1.42% for Type 3 gold alloys, 2.30 for Type 4 nickel-chrome based alloys and 2.30 for cobalt-chrome based alloys [3]. The size and shape of the casting as well as the high heat compressive strength of the investment are also recognized as factors that

could influence the percentage of linear solidification shrinkage [4, 5]. Price reported a solidification shrinkage of 2.2% for gold alloys, Shell 1.71%, Coleman 1.25% and Hollenback & Skinner 1.3% to 1.5% [6, 7]. In these studies the shrinkage of the alloy was calculated indirectly by directly measuring the dimensions of the wax pattern and the casting and correcting for investment expansion. One major disadvantage was that since their wax patterns were bars and rods, they had no clinical relevance. Fusayama devised an accurate technique for an indirect calculation of the solidification shrinkage and showed that it can be affected by the shapes and sizes of the castings [8]. Fusayama & Ide in their study of the shrinkages of gold alloys determined the percentage of shrinkage to 1.9% to 2.1% for Type 1 alloy and 1.8% to 1.9% for Type 2 and Type 3 alloys for single restorations [9]. They employed an indirect calculation technique which minimized wax pattern distortion before and after removal from the die and by utilizing an experimental investment with minimal setting expansion which was close to isotropic in nature thanks to the use of an asbestos liner in the casting ring with sufficient thickness. Furthermore, in a subsequent study by Fusayama and Kono [10], the solidification shrinkage of Type 3 gold alloys was calculated to be 1.5% for vertical molds and 1.5% for horizontal molds. The solidification shrinkage of lithium disilicate is calculated using the coefficient of thermal expansion of the material, which is reported to be $10.55 \times 10^{-6} \text{K}^{-1}$ for the 100°-500° C range.

Investment materials have different ways of achieving the desired expansion. Ideally, the total setting and thermal expansion should equal the solidification thermal contraction of the material used for the casting [11,12]. Type I gypsum-bonded investments counteract

the solidification shrinkage of the alloy by means of thermal expansion. Type II gypsum-bonded investments achieve solidification shrinkage compensation by means of hygroscopic expansion, which occurs as they are permitted to set immersed in a water bath. Phosphate-bonded investments utilize both setting and thermal expansion. Hygroscopic expansion is a result of surface tension. During the initial setting reaction, the precipitated gypsum crystals are enclosed in a film of water. The surface tension of this film of water prevents the crystals from growing further [13]. If the investment material is placed in a waterbath after it has achieved green strength, the surface tension and the friction between the crystals diminishes and the crystals are allowed to expand [14]. In this sense, hygroscopic expansion can be considered an unhindered setting expansion. Both gypsum-bonded and phosphate-bonded investment materials show hygroscopic expansion. Setting expansion and hygroscopic expansion are important with gypsum bonded investments because thermal expansion is limited. The burn-out temperature is not high enough to ensure adequate thermal expansion. And if it were raised further for alloys with higher melting points then the water molecules between the layers of calcium sulphate would be eliminated at two very specific temperature ranges; from 200° - 230° C and 270° - 350° C [14, 15]. This would cause a collapse of the structure that would be manifested macroscopically as a shrinkage of the mould cavity. Furthermore, in order to ensure adequate thermal expansion the temperature would have to be elevated to levels at which the gypsum binder would start to deteriorate. From 700° C to 900° C the binder starts to break down. Calcium sulphate reacts with the silica in

the presence of heat producing calcium silicate and sulphur trioxide gas. This material deterioration is not an issue with phosphate bonded investments [14, 15].

In phosphate bonded investments, the refractory material is quartz, cristobalite or both. Magnesium oxide and phosphoric acid or mono ammonium phosphate is the binder.

Colloidal silica solutions mixed with water in different ratios for different applications provide an additional source of expansion to counteract the greater solidification contraction resulting from the higher melting range of the alloys employed. In phosphate bonded investments, the expansion that is the result of the formation of magnesium ammonium phosphate hexahydrate during the setting reaction is called setting expansion [16, 17, 18]. Jorgensen & Okamoto reported that the main drawback of phosphate bonded investments is the fact that their setting expansion is influenced by many factors (the measuring technique, the measuring force applied to the investment, the amount of time that passes from the end of mixing to the beginning of measuring the expansion, temperature, the powder/liquid ratio, the type of liquid used, the mixing device, the material volume, mixing time, the use of a casting ring and the type of liner) [11, 12, 13]. In addition, Santos & Ballester reported that the setting expansion of phosphate-bonded investments can be significantly affected by changes in environmental humidity and temperature, even after the investment's final set [19, 20]. According to Stevens, dimensional changes in castings can be the result of the way they are positioned in the casting ring, due to settling and packing of silica particles [21]. Lengthy patterns are more prone to such casting inaccuracies, especially when significant vibration is applied, something that may be required with long casting rings [22, 23]. According to Jones,

setting expansion is more prone to variations and is less consistent than thermal expansion [15]. A significant range of values of setting expansion can be obtained depending on the conditions of restraint of the investment and water availability. The phosphate salts used as a binder are significantly hygroscopic in nature and despite the fact that this category of investments is not typically used with the technique of hygroscopic expansion a significant absorption of water is possible, one that could cause bloating until cracking and ruptures could occur [14, 15].

Gypsum bonded investment materials were traditionally used with a metal casting ring. This was necessary because the green and high temperature strength of the gypsum bonded investments was not adequate. Liners of various compositions were also routinely used in combination with the casting ring in order to limit the restriction of the investment's setting expansion. Earnshaw reported that if the setting expansion surpasses the amount the liner permits, then the radial restriction provided by the casting ring walls will direct the expansion in an axial direction [24]. As a result the length of the mould cavity will increase and the casting will be distorted. The effect of utilizing lined or unlined casting rings on the dimensional changes of investments and castings has been examined by several authors [25, 26, 27]. They all concluded that unlined casting rings produce undersized castings. Rice and Morgano reported that the restraining effect of an unlined casting ring directed the setting expansion inwards, producing undersized castings in a radial direction [28, 29]. Morgano also stated that this might be beneficial for investing and casting patterns for intra-coronal casting such as cast post and cores or inlays, since a slightly undersized cast post and core will allow for cement space and a

more passive fit, with less chance of vertical root fractures and catastrophic failures [28]. Otun concluded that investing without a casting ring liner and utilizing a final burn-out temperature of 600° C resulted in the fabrication of cast posts and cores that require significantly less chair side adjustment time than those cast in a lined casting ring with a burn-out temperature of 815° C [30]. Junner & Stevens demonstrated the anisotropic setting expansion of three phosphate-bonded investments when the casting ring technique was utilized [31]. The thermal expansion of the casting ring is significantly different from that of the investment material resulting in distorted castings of reduced diameter and increased length. According to Fusayama's study of investment expansion in casting rings, the setting expansion is influenced by the restrictive stress exerted on the investment [10]. Jack and Cruickshanks-Boyd reported that the thermal expansion of the phosphate bonded investments that they examined was not affected by the heating rate or the age of the set investment but were extremely sensitive to the level of restricting stress of casting rings and liners [32]. Jorgensen & Okamoto concluded that the setting expansion of phosphate bonded investment materials in casting rings, lined or unlined, with one or multiple layers of liners, pretreated or not with water or vaseline is a significantly unreliable method to partly compensate for the solidification shrinkage of alloys [12].

Phosphate bonded investments on the other hand are capable of achieving adequate green and high temperature strength, thus making the use of a rigid casting ring unnecessary. In this "Ringless" approach, a soft plasticized PVC ring contains the investment material until it has reaching the initial set. This PVC ring is then removed

and the investment enters the burn-out furnace without it. Lloyd reported that the elastic PVC rings in the “Ringless” technique limit the radial restrictive stress and permit greater radial setting expansion and less axial setting expansion [17, 18]. This more isotropic pattern of expansion is considered to produce castings with less distortion. Junner and Stevens stated that when a rigid ring was employed the axial expansion was significantly higher than the radial expansion and that they were not significantly different when a flexible ring was used [31].

Various authors have recognized the unreliable nature of setting expansion of phosphate bonded investment materials as a means of achieving the necessary expansion, along with the thermal expansion, to compensate for the total percentage of solidification shrinkage of the alloys used for casting. Lloyd reported that setting expansion builds to a certain extent and continues at a reduced rate beyond the time at which many technicians commence the burn-out process in the furnace [16, 17]. Stevens stated that usually it is convenience that dictates when the burn-out process begins and that this varies significantly [22]. In his study the setting expansion of phosphate bonded investments continued for more than six hours. Investments heated to 100° C within six hours of the beginning of mixing expanded fast and the rate of expansion was greater when the time between mixing and heating was reduced and when greater concentrations of colloidal silica solutions were employed. This rapid expansion was interpreted as a combination of thermal and accelerated setting expansion. Jones & Wilson reported that accelerated heating of dry calcium sulphate bonded investment materials resulted in significantly

less thermal expansion [14, 15]. Phosphate bonded investments on the other hand were unaffected by accelerated heating [15].

Due to this unreliable setting expansion behavior of investment materials several authors have concluded that the ideal investment material should exhibit minimum setting expansion and that the total percentage of expansion necessary to compensate for alloy shrinkage upon cooling should be achieved by means of thermal expansion. Some even attempted to formulate experimental phosphate bonded investment materials with these characteristics. Watanabe stated that the setting expansion of dental investment materials should be minimal to prevent distortion of the invested wax pattern and that the thermal expansion should be high enough in order to compensate completely for the shrinkage of the alloy upon cooling [33]. Stevens & Jorgensen described the setting chemical reaction of investment materials as exothermic and stated that the heat produced during this reaction could distort the wax pattern, along with the possible anisotropic expansion of the mould cavity [11, 12, 21]. Their findings indicated that when aqueous glycerol solutions were used the setting expansion was close to zero, yet the distortion of the wax patterns was considerable, a finding that was attributed to wax stress relaxation as a result of the heat of the exothermic reaction. Jorgensen & Okamoto concluded that the use of colloidal silica special liquids should be avoided with phosphate bonded investments in an attempt to minimize setting expansion and wax pattern distortion [12]. They advocated the use of water or an aqueous glycerol solution in order to achieve adequate thermal expansion [12]. Junner & Stevens stated that new types of phosphate bonded investments should be developed that will exhibit lower setting expansions. The

necessary total expansion should be obtained by means of an increased thermal expansion instead [31]. In 1981, Finger reported on the use of an gypsum bonded investment material with minimal setting expansion and adequate unrestricted thermal expansion. The disadvantage of this material was its limited applicability since it is not suitable for casting alloys routinely used in metal ceramic technology that require elevated casting temperatures [34]. On the same note, in 1986 Jorgensen & Watanabe published a study on a new experimental phosphate bonded investment with minimal setting expansion of 0.03-0.05% at 24h after mixing [35].

Therefore, there is limited data regarding the setting expansion of routinely used commercially available investment materials for casting alloys for porcelain fused to metal restorations, removable dental prosthesis frameworks and heat pressed lithium disilicate restorations. Interestingly, the ADA Specification No. 42 does not specify setting expansion percentages for phosphate-bonded investment materials [4]. Ideally, the setting expansion of these investment materials should be close to zero and the thermal expansion adequate to compensate for the total solidification shrinkage of the casting material. If minimal setting expansion cannot be achieved, there is limited data as to whether it is possible for the material to achieve setting expansion adequate for solidification shrinkage compensation, when combined with the material's thermal expansion. In addition, there is limited data as to whether the necessary percentage of setting expansion is achieved at the time proposed by the manufacturer for burn-out. Furthermore, the behavior of these investment materials from a setting expansion standpoint has not been determined if the burn-out time is delayed beyond the

manufacturer's recommendation as casting convenience for the dental technician might necessitate.

The purpose of this study was to investigate the setting expansion characteristics of three commercially available phosphate bonded investment materials for casting high fusing alloys and heat pressed ceramic lithium disilicate. Four null hypotheses were tested.

The first null hypothesis of the experiment was that there would be no setting expansion of the investments at the burn-out time proposed by the manufacturer.

The second null hypothesis of the experiment was that there would be no difference in setting expansion from the one reported by the manufacturer, at the time recommended for burn-out.

The third null hypothesis of the experiment was that there would be no difference in the setting expansion measured (at the burn-out time proposed by the manufacturer) from the setting expansion required to fully compensate for the solidification shrinkage of the various alloys and pressable ceramics.

The fourth null hypothesis was that there would be no difference in the setting expansion measured at the burn-out time proposed by the manufacturer from the expansion at delayed burn-out times (4, 6, 12 & 24h after mixing).

2. MATERIALS AND METHODS

The three investment materials tested were: FastFire 15 (Whip Mix, Louisville, Ky.), Powercast (Whip Mix, Louisville, Ky.) and IPS PressVest Speed (Ivoclar Vivadent AG, 9494 Schaan/Liechtenstein) (Table 1) . Twenty specimens per group were poured in a trough that conformed to ADA Specification No. 2 for the measurement of the linear setting expansion of gypsum bonded investments (Figure 1) . The resulting specimens were 100mm in length and triangular in cross section (33x50x33 mm) at the time of pouring. Since ADA Specification No. 42 for phosphate bonded investments does not specify a measurement device for the setting expansion of these materials, the measuring protocol specified by the ADA for gypsum bonded investments was employed (ISO 6893) [5]. All investment materials were stored in an environment that conformed to the manufacturer's recommendations. The room temperature was maintained at 70° C (+-5) and the deionized water used for the colloidal silica solution was maintained at a temperature of 78° C (+-2). Standardized humidity conditions were not established in order to realistically represent conventional dental laboratory settings.

Dedicated mixing bowls (Whip Mix, Louisville, Ky.) were used that were rinsed with deionized water prior to mixing each specimen and air dried to remove all the residual water. The powder was added to the liquid for each specimen and the mixture was hand spatulated according to the manufacturer's recommendations. Specifically, Powercast specimens were hand spatulated for 20 seconds, FastFire 15 for 15 seconds, PressVest Speed for 20 seconds. Even wetting of the powder was achieved. Powercast was then

mechanically mixed under vacuum at 350-450 RPM for 90 seconds, FastFire 15 at 350-450 RPM for 60 seconds and PressVest Speed at 350 RPM for 150 seconds. The Whip Mix VPM2 Mixer (Whip Mix, Louisville, Ky.) was employed. Powder/liquid ratios and Special Liquid concentrations were determined according to the manufacturers' recommendations for different applications. The following 5 groups were established and are listed in Table 1.

After mixing each investment material was immediately poured into the V shaped trough of the expansion gauge (EMI 300; SAM Prazisionstechnik GmbH, Munich, Germany) which was lined with rubber dam (Hygenic Dental Dam; Coltene/Whaledent, Mahwah, N.J.) (Figure 1) . The rubber dam prevents direct contact of the investment material with the walls of the V-shaped trough and minimizes any friction, which would restrict the linear expansion of the investment material. The linear expansion of each specimen was measured with a Mitutoyo IDS-1012B Digimatic Indicator with the ability to measure changes from 0.01-12mm (Mitutoyo Corporation, Japan). According to the Mitutoyo Corporation the Digimatic Indicator exerts 1.5N or less to the expanding plate of the V shaped trough. Expansion was measured at 2, 4, 6, 8, 12, 24h after mixing (Table 3). It was measured in mm and expressed in a percentage through the formula $E/L \%$ where E is the measured expansion at each one of the six time interval and L the initial length of 100mm. Expansion data were transferred to the computer using a SmartCable device (Advanced Systems & Designs, Greystone Industries LLC, Model # 600-390-KB-USB, Firmware: v2.2) (Figure 2). Data were recorded in .txt files in a Microsoft Windows XP PC and then converted to .xls files in Microsoft Excel.

The manufacturer's recommended burn-out times, the delayed burn-out times, the manufacturer's reported linear setting expansion and the linear solidification shrinkage of the alloys and lithium disilicate are shown in Table 2, 3 & 4.

Statistical analysis was performed with SPSS v11.5 (SPSS Inc., Chicago IL).

A one sample T-test was performed to:

- a) Determine whether the setting expansion measured at the manufacturer's recommended time for burn-out was statistically significant,
- b) Compare the setting expansion measured at the manufacturer's recommended time for burn-out with the setting expansion reported by the manufacturer,
- c) Compare the setting expansion measured at the manufacturer's recommended time for burn-out with the setting expansion required to fully compensate for the solidification shrinkage of the alloys and pressable ceramic

A One-way ANOVA test was performed to compare the setting expansion measured at the manufacturer's recommended time for burn-out with the setting expansion at delayed burn-out times, namely at 4, 6, 8, 12 and 24 hours after investing. When a difference was detected, a post-hoc analysis was performed using the Tukey HSD test. The statistical significance level was set at $P \leq 0.05$.

3. RESULTS

Means for the setting expansion of each experimental group were calculated from the measurements collected at 2 hours, 4 hours, 6 hours, 8 hours, 12 hours and 24 hours.

These means and standard deviations are shown for all groups in Tables 5-9.

A one sample T-Test showed that the setting expansion measured for all of the experimental groups was statistically significant ($P \leq 0.01$).

A one sample T-Test indicated that all of the groups exhibited statistically significant differences in setting expansion at the manufacturer's recommended burn-out time, namely 2 hours, from the setting expansion reported by the manufacturer ($P \leq 0.01$). All of the groups exhibited setting expansion greater than the one reported by the manufacturer.

A one sample T-Test showed that all of the groups exhibited statistically significant differences in setting expansion at the manufacturer's recommended burn-out time, namely 2 hours, from the setting expansion required in order to fully compensate for the solidification shrinkage of the various alloys and the pressable ceramics with which the various investment materials are used ($P \leq 0.01$). P90, P60, FF50 and PVS expanded less than what is required in order to fully compensate for solidification shrinkage during the casting procedures. FF75 was the only group that managed to fully compensate for the solidification shrinkage of the alloy it is intended for.

One-way ANOVA was calculated to compare the setting expansion at delayed burn-out times (Table 11). Levene's test of homogeneity of variances was satisfied ($P \geq 0.05$)

(Table 10). The ANOVA did not reveal a statistically significant difference in setting expansion at delayed burn-out times for P90, P60, FF75 & FF50 (Figures 3, 4, 6, 7). The ANOVA revealed a statistically significant difference in setting expansion at delayed burn-out times for PVS ($P \leq 0.01$) (Figure 5). A post-hoc analysis for PVS using the Tukey HSD test revealed that there was a statistically significant difference in setting expansion between two sets of subgroups: 2 and 4 hours groups on one hand and the 6 hours, 8 hours, 12 hours and 24 hours groups on the other ($P \leq 0.03$ for the 6 hours group and $P \leq 0.01$ for the 8 hours, 12 hours and 24 hours groups). The dimension of the PVS specimens did not change significantly after 4 hours (Figure 5).

4. DISCUSSION

In this in vitro study, the setting expansion of five experimental groups for various applications was investigated. This study proved that the investment materials examined in the various groups exhibit setting expansion. According to Watanabe, this is important since ideally an investment material should mainly exhibit thermal expansion and only minimal or negligible setting expansion [33]. As discussed in the review of the literature, setting expansion is the type of expansion that is more variable, influenced by a greater number of factors and is more difficult to standardize and control compared to thermal expansion. There have been attempts in the past to create investment materials with ideal behavior in terms of expansion by trying to limit their setting expansion. These investments would theoretically compensate for the solidification shrinkage that occurs during the casting procedures by means of thermal expansion only. This has not been possible yet.

This study also assessed the accuracy and reproducibility of the measurements of setting expansion provided by the manufacturers. The statistical analysis proved that these values are indeed different from the ones the manufacturers report. This was possible due to the highly controlled conditions of the experiment, as the homogeneity of variance for the various groups shows.

An attempt was also made to determine whether the investment materials examined could provide the necessary expansion in order to compensate for solidification shrinkage and produce an accurate casting. Within the limitations of this study, it was

shown that this was not possible. All of the groups expanded less than the required amount, except for FF75, which showed a greater amount of expansion. The literature review conducted by the author revealed the numerous attempts by other investigators in the past to provide percentages of solidification shrinkage for the various materials used in casting procedures. This literature review also revealed the complexity of attempting such calculations, as solidification shrinkage can be influenced by the shape and size of the castings, the high heat compressive strength of the investment material, wax pattern expansion, die size, even the manner of investing in a horizontal or a vertical mold. For the purposes of this study the percentages reported in the widely accepted “Phillips’ Science of Dental Materials” text were used [1] (Table 4).

This study also investigated the setting expansion at delayed burn-out times (Table 3). It proved that for PVS a delayed burn-out time after 4 hours from mixing resulted in a significant difference in setting expansion. No significant differences in setting expansion at delayed burn-out times could be detected for the rest of the experimental groups. A greater number of specimens for these experimental groups could potentially provide enough statistical power in order to confirm the absence of a statistical difference, yet that number of specimens was beyond the limitations of this in vitro study.

There are several implications in the daily practice of a dental laboratory. Much like with most other dental laboratory materials, investment materials require close monitoring in terms of the timing of the procedures. Since it is usually convenience that dictates the timing and sequencing of the various investing and casting procedures in the busy

schedule of a dental laboratory, knowing the dimensional behavior of the material used is critical. Within the limitations of this study, it can be noted that delayed burn-out time for PVS past the manufacturer's recommended time could result in significantly greater setting expansion of the investment material. Whether this could result in clinically significant differences in the restorations produced remains to be determined in a different study. No general statement can be made for the other experimental groups, yet within the limitations of this study their dimensional behavior in terms of setting expansion appears to be more stable for the first 24h after the recommended burn-out time. Furthermore, other factors that affect the dimensional characteristics of the casting, like the expansion of the die stone, the die spacer thickness and the dimensional behavior of the invested wax pattern should be further assessed and adjusted accordingly in order to fully compensate for the solidification shrinkage of the various alloys or pressable ceramics. Future directions for other studies on the topic of dental casting and investment materials could include examining the grain size of the each investment material used, since this is another very important factor that influences the initial adjustments of the casting in the dental laboratory and potentially the fit of the casting intra-orally and how that grain size could potentially change with delayed burn-out times. Optical inspection of the various specimens in this study at delayed burn-out times revealed a noticeable change in appearance, roughness of the surface and potentially a change in grain size, all of them factors that could affect the quality of the produced casting.

5. CONCLUSIONS

Within the limitations of this in vitro study, the following conclusions can be drawn:

1. The setting expansion measured for all groups was statistically different from the one reported by the manufacturer, for the recommended burn-out time.
2. P90, P60, FF50 and PVS expanded less than what is required in order to fully compensate for solidification shrinkage during the casting procedures. FF75 was the only group that managed to fully compensate for the solidification shrinkage of the alloy it is intended for.
3. The delayed burn-out times evaluated in this study resulted in significantly greater setting expansion for PVS.

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APPENDIX A - FIGURES



Figure 1. Mitutoyo Digimatic expansion gauge with V shaped trough lined with rubber dam.



Figure 2. SmartCable for data transfer to computer

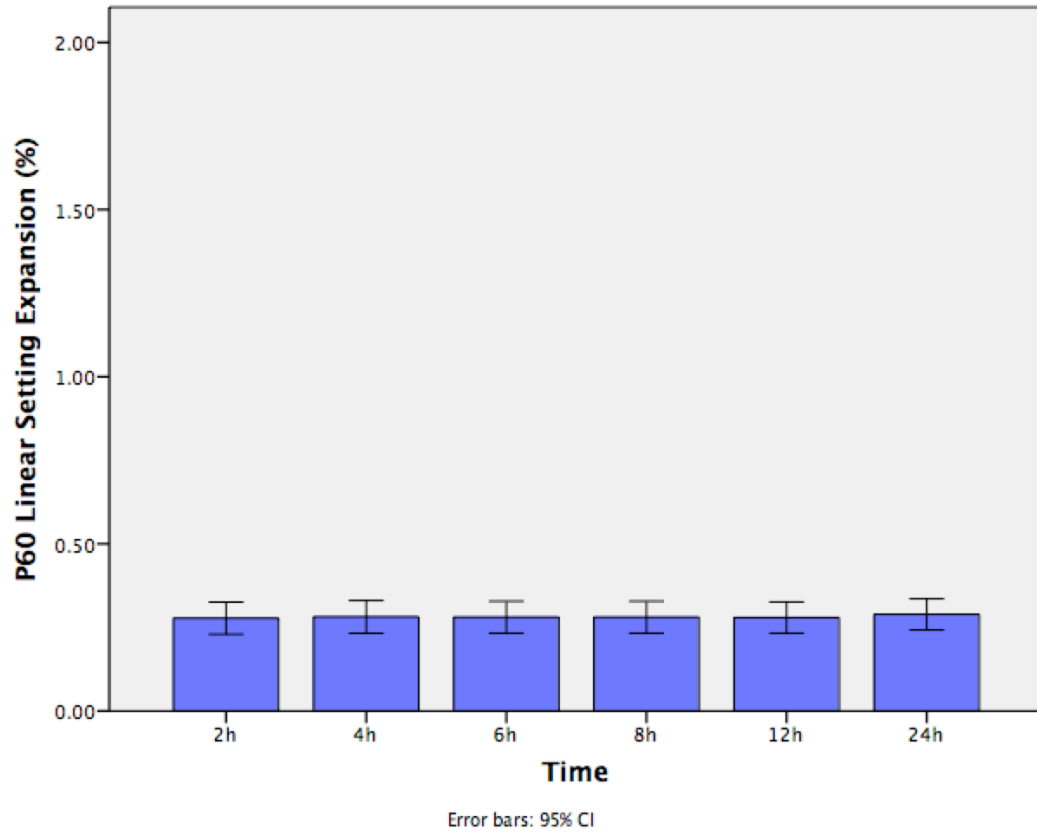


Figure 3. P60 Mean setting expansion (%) & SD at delayed burn-out times

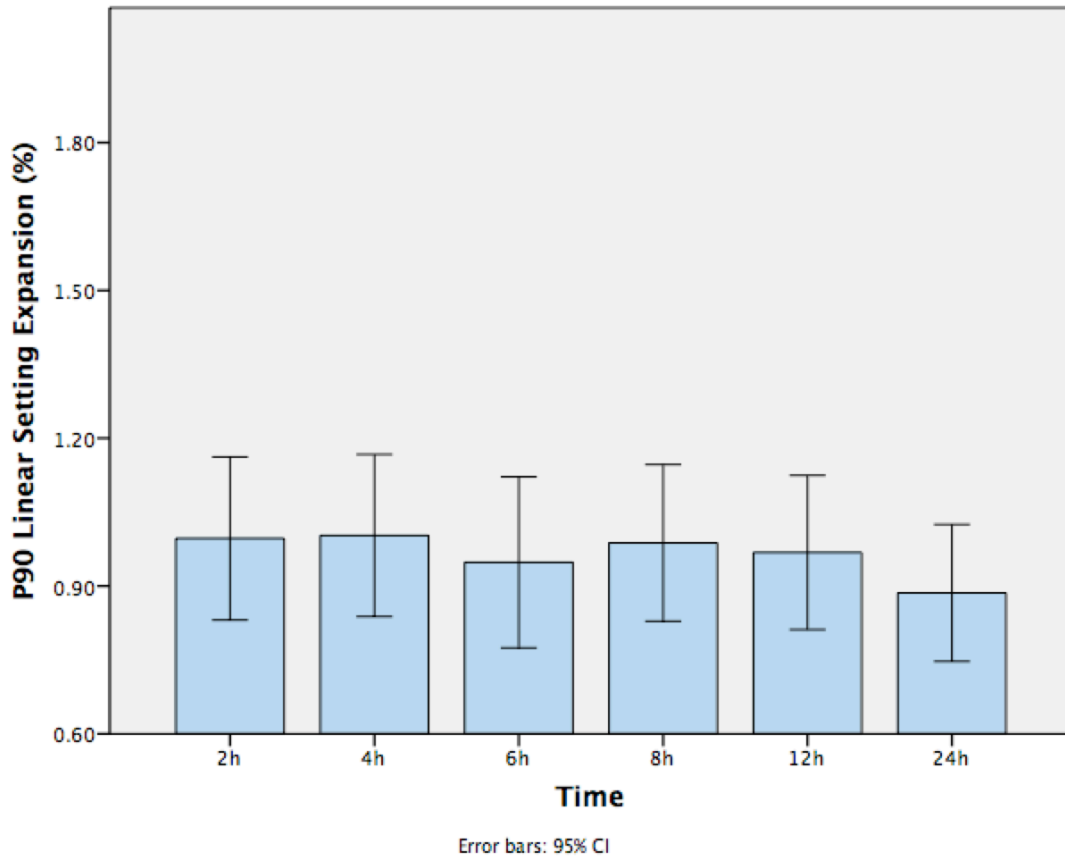


Figure 4. P90 Mean setting expansion (%) & SD at delayed burn-out times

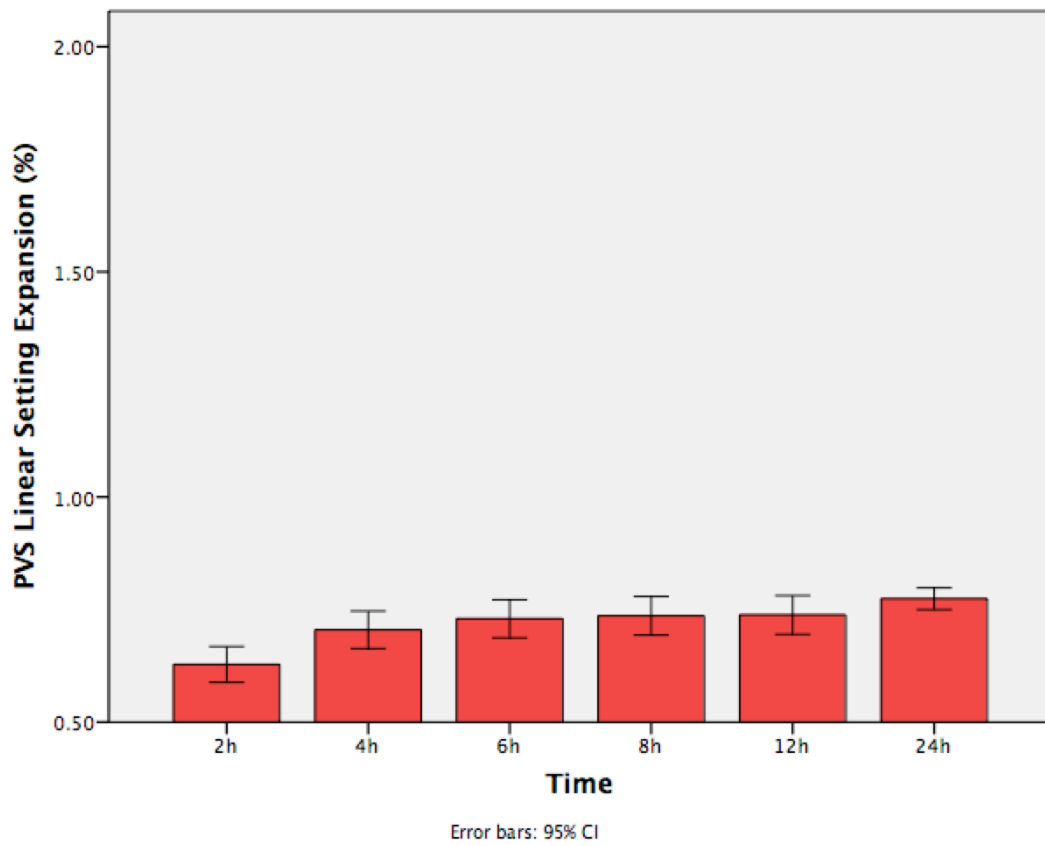


Figure 5. PVS Mean setting expansion (%) & SD at delayed burn-out times

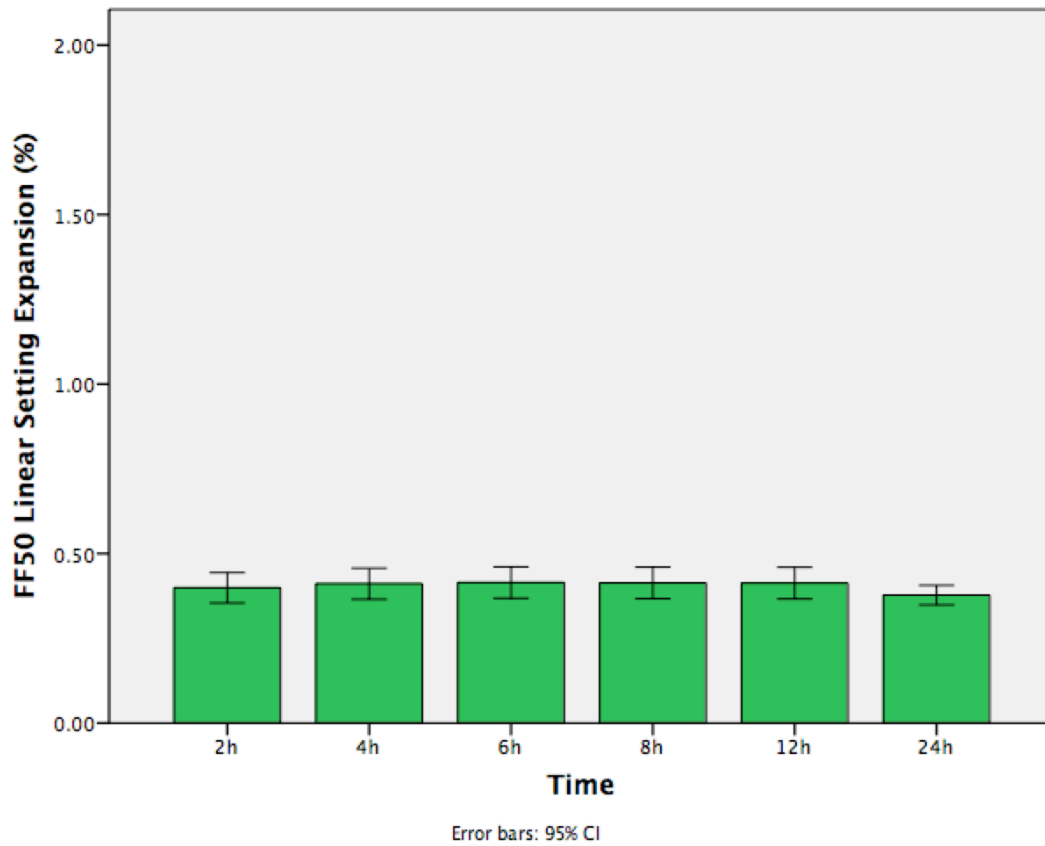


Figure 6. FF50 Mean setting expansion (%) & SD at delayed burn-out times

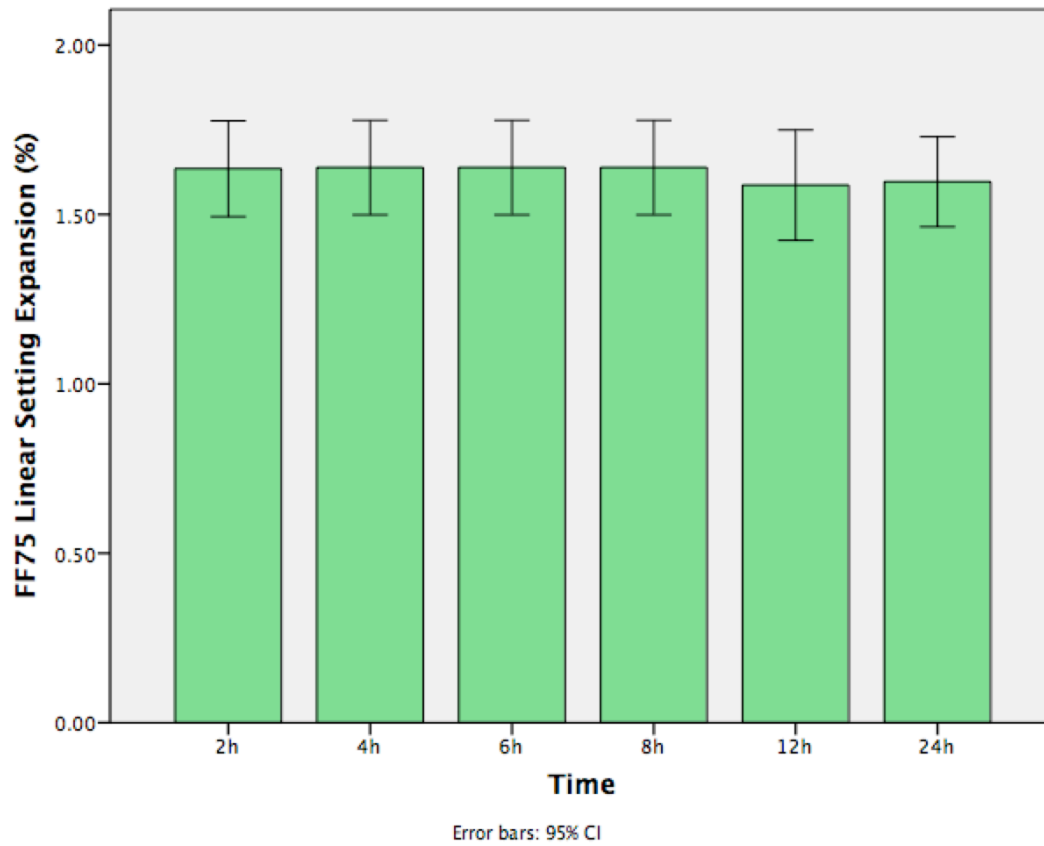


Figure 7. FF75 Mean setting expansion (%) & SD at delayed burn-out times

APPENDIX B - TABLES

Table 1. Experimental groups

Group	Description
P90	Powercast 100g/23mL – 90% Special Liquid for Cobalt-Chrome alloys LOT 074101401
P60	Powercast 100g/23mL – 60% Special Liquid for High Noble Gold alloys LOT 074101401
FF75	FastFire 15 100g/27mL – 75% Special Liquid for Cobalt-Chrome alloys LOT 072061601
FF50	FastFire 15 100g/27mL – 50% Special Liquid for High Noble Gold alloys LOT 072061601
PVS	PressVest Speed 100g/27mL – 60% Special Liquid for Lithium Disilicate Veneers, Partial Crowns and Single Crowns LOT VL 1766

Table 2. Manufacturer's reported linear setting expansion percentages

Investment Material	Manufacturer's reported Linear Setting Expansion at 2h (%)
P90	1.2
P60	0.22
FF75	1
FF50	1
PVS	Not reported

Table 3. Burn-out times

Investment Material	Manufacturer's Recommended Burn-Out Time	Delayed Burn-Out Times
P90	1.5 - 2 hours	4, 7, 8, 12, 24 hours
P60	1.5 - 2 hours	4, 7, 8, 12, 24 hours
FF75	1 - 2 hours	4, 7, 8, 12, 24 hours
FF50	1 - 2 hours	4, 7, 8, 12, 24 hours
PVS	1.5 - 2 hours	4, 7, 8, 12, 24 hours

Table 4. Linear solidification shrinkage percentages [3]

Material	Solidification Shrinkage (%)
High Noble PFM Alloys	1.42
Cobalt-Chrome Alloys	2.3
Lithium Disilicate	0.791

Table 5. P60 mean setting expansion & SD

Time (hours)	Mean Setting Expansion (%)	Standard Deviation (%)
2	0.277	0.102
4	0.281	0.104
6	0.280	0.102
8	0.280	0.102
12	0.279	0.99
24	0.279	0.99

Table 6. P90 mean setting expansion & SD

Time (hours)	Mean Setting Expansion (%)	Standard Deviation (%)
2	0.99	0.353
4	1.00	0.351
6	0.948	0.370
8	0.987	0.339
12	0.968	0.334
24	0.886	0.296

Table 7. PVS mean setting expansion & SD

Time (hours)	Mean Setting Expansion (%)	Standard Deviation (%)
2	0.628	0.085
4	0.705	0.088
6	0.729	0.090
8	0.736	0.091
12	0.738	0.091
24	0.774	0.051

Table 8. FF50 mean setting expansion & SD

Time (hours)	Mean Setting Expansion (%)	Standard Deviation (%)
2	0.399	0.095
4	0.411	0.098
6	0.414	0.099
8	0.413	0.099
12	0.413	0.099
24	0.377	0.061

Table 9. FF75 mean setting expansion & SD

Time (hours)	Mean Setting Expansion (%)	Standard Deviation (%)
2	1.635	0.302
4	1.638	0.298
6	1.638	0.298
8	1.638	0.298
12	1.586	0.348
24	1.596	0.283

Table 10. Test for homogeneity of variances

Group	Levene Statistic	df1	df2	Sig.
P60	0.011	5	114	1.000
P90	0.231	5	114	0.948
PVS	0.668	5	114	0.649
FF50	0.641	5	114	0.669
FF75	0.242	5	114	943

Table 11. One-way ANOVA

	Sum of Squares	df	Mean Square	F	Sig.
P60				.030	1.000
Between Groups	.002	5	.000		
Within Groups	1.183	114	.010		
Total	1.185	119			
P90				.323	.898
Between Groups	.189	5	.038		
Within Groups	13.333	114	.117		
Total	13.522	119			
PVS				6.865	.000
Between Groups	.245	5	.049		
Within Groups	.814	114	.007		
Total	1.060	119			
FF50				.485	.787
Between Groups	.021	5	.004		
Within Groups	.991	114	.009		
Total	1.012	119			
FF75				.124	.987
Between Groups	.058	5	.012		
Within Groups	10.641	114	.093		
Total	10.699	119			