THE EFFECT OF POURING METHOD AND STORAGE CONDITIONS ON DENTAL IMPLANT MODEL DISTORTION

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DECLARATION

I, Alexander Rawháni, declare that this research report is my own work. It has been submitted for the degree of Master of Science in Dentistry in the Faculty of Health Sciences at the University of the Witwatersrand, Parktown, Johannesburg, South Africa. It has not been submitted before for any other degree or examination at this or any other University

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This 13th day June 2016

In memory of my beloved mother,
Shohreh Youssefián-Rawháni.
Mommy Joon
1954-2014

ABSTRACT

Aim: To compare two different cast pouring methods and their storage in the first 24 hours for their accuracy in reproducing a master model of four implant fixtures set at different heights, and to determine whether any distortion would occur over 90 days.

Methods and materials: Twenty casts were made from the same batch of type IV dental stone. Ten were poured using the single-pour technique and ten were poured using a cylinder technique. Within each of these groups, 5 casts were randomly selected to be placed into sealed plastic bags for the first 24 hours to ensure maximum humidity; the remaining 5 were left for 24 hours on the laboratory bench. The position of each analogue in each cast was then measured using a Reflex Microscope. All casts were then measured at 3-week intervals and finally at 90 days.

Results: There were no statistically significant differences in the overall mean values under all conditions. Four casts displayed some positional differences of some analogues, some greater and some less than 150 µm. However, these were insufficient to influence the null hypothesis that there would be no difference in pouring, storage method or their interaction either initially or over time.

Conclusions: There appears to be no benefit in using a two-step cylinder method for pouring implant analogue casts, or for their initial storage under humidity, provided that the correct measuring and mixing of the gypsum is carried out. Under the conditions of this study, keeping the casts in a laboratory environment for 90 days would appear not to be detrimental.

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

INTRODUCTION AND LITERATURE REVIEW

1.1. Background to the study

Casts poured from impressions for the fabrication of the superstructure framework of an implant supported prosthesis (ISP) need to be extremely accurate in order to successfully fit the framework onto the intra-oral fixtures. Once the prosthesis has been constructed and fitted on the patient, the casts are then stored in the laboratory or in the dental practice and are often used again to re-make the superstructure framework if the ISP should suffer any damage.

However, if used again, the passive fit of the superstructure could be compromised if there is significant cast distortion. Rodrigues et al. (2012) remarked that the longevity of treatment of ISPs is closely related to a precise adaptation between the prosthetic components and its fixations (implants) and that the absence of passivity would induce excessive tension on the implants and supporting bone, leading to bone resorption and eventual prostheses loss (Rodrigues et al., 2012). Different pouring methods and storage conditions can affect the dimensional stability and accuracy of these casts.

A study conducted by McCartney and Pearson (1994) investigated the pouring of a small amount of gypsum around implant analogues in order to improve precision. A two-stage latex cylinder pouring technique was also introduced by the commercial company Nobel Biocare (Del Acqua et al., 2008), in an attempt to reduce the expansion distortion caused by a great volume of dental stone. Rodrigues et al. (2012) set out to determine the precision of master casts using 3 different pouring methods. Rodrigues et al. (2012) investigated alternative methods of pouring implant casts in order to find a method which would result in minimal dimensional change of the master cast. These authors proposed that this would provide better accuracy, structure fit and passive fit without any induced tensions to the bone or implant. The study by Rodrigues et al. (2012) had limitations in that the gypsum was mixed by hand and not controlled by machine mixing. Difficulty was also observed in placing gypsum in the cylinder-created holes at the second stage of the cylinder pouring technique, leading to increased difficulty and a higher percentage of failures (Rodrigues et al., 2012).

1.2. Gypsum in Dentistry

Type IV high strength dental stone, also known as die-stone, conforming to the American Dental Association (ADA) Specification 25 (ANSI/ADA, 1987) was used in this study (Santos et al., 1984). This type of stone is a low expansion gypsum composed of modified alpha-hemihydrate cube-shaped particles, which because of their reduced surface area, produce properties such as strength, hardness, less surface abrasion and minimal setting expansion without undue thickening of the mix (Santos et al., 1984). The maximum range of setting expansion of die stone as defined by the ADA specification is 0.1% (ANSI/ADA, 1987). A low expansion die stone is defined as one that expands by no more than 0.1%. A high expansion dental stone expands more than 0.1% (Millstein, 1992).

1.3. Distortion of gypsum

A variety of factors have the potential to create distortion in dental stone, such as the temperature and humidity of the environment, storage conditions of the unmixed powder, the temperature of the water used, the water / powder ratio, and the mixing time (Anusavice et al., 2013). An early study determined dimensional changes when dental stone was subjected to conditions found in a dental practice, and found that no significant dimensional change occurred as a result of storage of the casts under "normal" laboratory conditions (63% humidity and 25°C temperature), but that an increase in temperature led to shrinkage (Sweeney et al., 1950). Small levels of distortion in a gypsum cast used to make an ISP can affect the fit of the prosthesis. Distortion values greater than 150 µm were reported to be clinically significant and may affect its passivity of fit and hence the longevity of the prosthesis (Jemt, 1991).

Studies by Lautenschlager et al. (1969) and Sweeney et al. (1950) have also provided information on the reaction of gypsum casts when set in terms of their expansion and contraction in air. The results showed that all gypsum models have an initial contraction then overall expansion. The volumetric contraction is associated with the setting of gypsum from calcium sulphate hemihydrate to dehydrate crystals (Winkler et al., 1998). Studies have also been carried out to determine the effect of hygroscopic expansion. Hygroscopic expansion leads to an increased expansion of the final cast, as the water normally consumed by the hydration process, which leads to the cast's initial contraction, is never lost and is constantly replenished by surrounding water leading to increased area for longer crystal growth, and thus, larger overall expansion (Santos et al., 1984).

Studies have also given insight into why it is not safe to store the unmixed gypsum powder in environments with a relative humidity greater than 70% (Kusner et al., 1967), or in environments with temperatures greater than 55° C (Anusavice et al., 2013). The effects of changes in recommended water-powder ratios have also been described by Lautenschlager et al. (1969), as well as the subsequent effect of this ratio on the cast setting expansion (Sweeney et al., 1950) which will be elaborated on in the sections below.

1.4. Gypsum Storage

Plaster stored at a relative humidity higher than 70% causes the plaster to ultimately absorb water from the air thus beginning its setting process and was described as "deadened" (Kusner et al., 1967). It has been recommended that gypsum should be stored in a dry atmosphere and should be sealed in a moisture proof container (Anusavice et al., 2013).

1.5. Water / Powder Ratio

The water / powder ratio (WPR) plays a large role in cast distortion and Type IV dental stone generally has a WPR of 0.22-0.24 (Alberto et al., 2011). The lower the WPR, the higher the powder content, which means the higher the setting expansion that will occur because more nuclei of crystallisation will be present (Alberto et al., 2011). A higher WPR leads to a decrease in the amount of crystal nuclei as fewer dihydrate crystals are present per unit volume, resulting in a faster setting time, increased porosity and decreased strength of the cast due to increased levels of evaporation (Anusavice et al., 2013).

1.6. Mixing of gypsum

The longer the mixing time, the faster the setting of the mixture, due to an increase in the presence of nuclei of crystallisation. If over-mixed however, the gypsum crystals will be broken up and the final product will hold less crystalline interlocking structures, leading to a decrease in cast strength. (Anusavice et al., 2013)

1.7. Storage of casts

If the storage temperature is raised between 90 °C and 110 °C, then shrinkage occurs along with loss of strength, as the water of crystallisation is removed and the dihydrate crystals revert back to their hemihydrate form, and as a rule of thumb, it is advised not to store or heat the stone in air at a temperature higher than 55 °C (Anusavice et al., 2013).

1.8. Conclusion

Current literature has linked cast distortion to WPRs and the mixing process, or the mixing technique and its relationship to the strength of the casts, but no studies have clearly investigated the differences between the distortion seen in casts as a result of different pouring techniques and immediate storage conditions nor the impact of those factors on cast distortion over time. There is also no information on whether the effect of storage conditions over months or years is actually of clinical significance. Storage of the casts would allow for the facilitation of a more cost effective and cost beneficial way of prosthesis repair and maintenance. This may preclude the taking of an additional impression, saving both time and money for the dentist and patient. This study will therefore investigate the effect of immediate storage conditions as well as pouring method on the accuracy of casts made from Type IV Gypsum and the amount of distortion over a period of 3 months, using a dental implant model as the control.

AIMS AND OBJECTIVES

2.1. Aim

To compare the accuracy of conventionally poured (one-step method) implant analogue casts with those poured using an alternate method (cylinder two-step method), and to compare the effect of an initial 24 hour post-pouring storage in 100% humidity versus bench storage, on the dimensional stability of the casts over a period of 90 days.

2.2. Objectives

- To establish consistency in the two different methods of cast pouring techniques.
- To provide baseline three-dimensional (3D) measurements of the positions of the implants in each cast.
- To store half the casts (n=10) in sealed plastic bags from pouring to 24 hours post pour.
- To store half the casts (n=10) under uncontrolled and fluctuant, but measured conditions of temperature and humidity from pouring to 24 hours post pour.
- To store all the casts (n=20) in the same fluctuant uncontrolled environment for 90 days, measuring the temperature, humidity and position of the implants at 2-3 week intervals.
- To analyse the effects of Method, Storage, and the Method-Storage interaction, on each outcome over a period of 90 days.
- To determine, for each outcome, whether any change results in a change of 0.15 mm.

2.3. Expected Outcome

To make recommendations on the most accurate method of pouring implant analogue casts, and to give factual guidelines on the best method of immediate cast storage and of their subsequent storage over 90 days.

2.4. Null Hypothesis

There will be no significant difference seen in terms of the distortion figures between the different methods of cast storage or the cast pouring methods.

3.1. Materials

- **Type IV Gypsum (**Pemaco™- Satin Stone Tan, Pemaco Incorporated, St Louis, MO, USA). Water/Powder Ratio (ml. to gm.) 19-100; Initial Set (minutes) 6.5-8.5. Type 4 dental stone is a high strength die stone with characteristics such as hardness and minimal setting expansion. It is made up of modified Alpha-hemihydrate cubed shape particles with reduced surface area, which contributes to its aforementioned characteristics without undue thickening of the mix.
- **4-fixture stainless steel implant master model** with implant analogues placed at different heights and in a conventional arch form (Southern Implants Irene, South Africa). This Master Model was custom made by Southern Implants for this research.
- **80 impression copings** (Southern Implants Irene, South Africa)
- **80 titanium implants** (Southern Implants Irene, South Africa)
- **Southern Implants torque wrench** (Southern Implants Irene, South Africa)
- **Special Tray light cure acrylic** (Megatray™, Megadent, Germany)
- **Polyether impression material** (Impregum™ 3M ESPE, USA). Impregum Penta is a hydrophilic, thixotropic medium bodied polyether precision impression material.
- **Dental Stone Vibrator**
- **Plastic high volume saliva ejector tubes** in place of the latex cylinders used by Rodrigues et al (2012)
- **Plastic 10ml syringe with** customised tip made from low volume saliva ejector tubes.
- **Reflex Microscope** (Reflex Measurement Ltd., Cambridge, UK)

- **Aquaspense™ SL mechanical dispenser and vacuum mixer** (VPM2)(Whipmix™, USA)
- **Thermometer and hygrometer (**Minema Laboratory Supplies, South Africa**)**

3.2. Method

A single stainless steel custom-made model with 4 implant fixtures at differing depths was created and used as the master model (MM) (fig. 3.1). The different depths ensured that the implant analogues would all be at different heights.

Figure 0.1 Master Model. The implant fixtures were numbered as shown on the right, to identify the distance and angle measurements.

Twenty impressions of the master model were taken under strictly controlled conditions and all 20 impressions were taken by a single operator, in a controlled dental laboratory environment. The impression material (*Impregum Penta*™) was mixed automatically in a *Pentamix*™ mixer and placed immediately into the pre-prepared special trays (fig.3.2).

Figure 0.2 Special Tray

The Special trays were standardised as follows: A 2mm thick thermo-formed acrylic spacer was made over the custom stainless steel model in order to ensure uniform spread and thickness of the impression material (fig 3.3). The same spacer was repeatedly used for the construction of the 10 special trays, which were all made from the same light-cured material in the same room under a controlled and monitored temperature by a single operator to decrease variance.

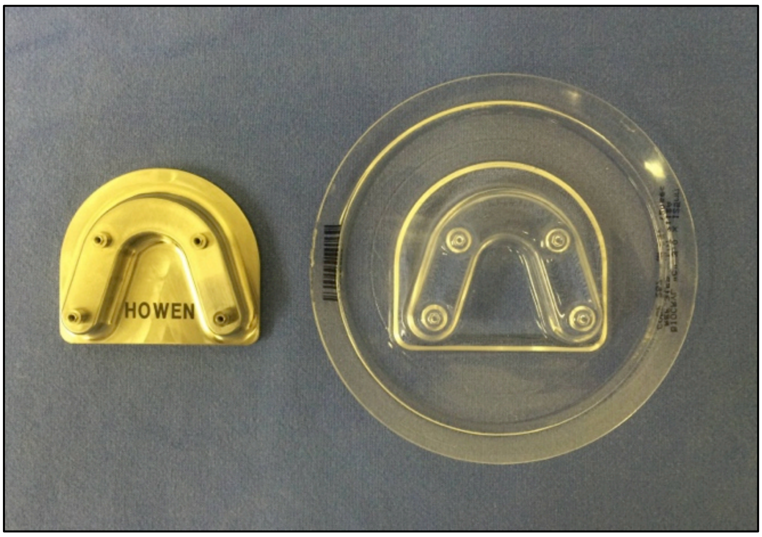

Figure 0.3 Master model with uncut 2mm acrylic spacer.

The 4 impression copings (fig 3.4) were then isolated with lab putty placed in high volume suction tubes to create a uniform thickness spacer around the impression copings in order to build the second part of the special tray around them (fig 3.5).

Figure 0.4 Impression copings.

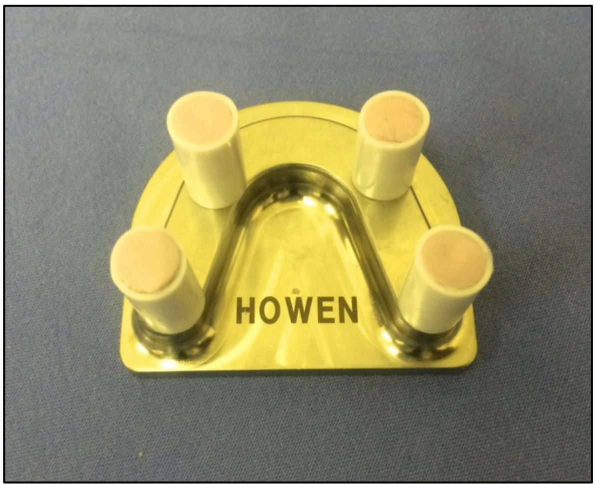

Figure 0.5 Impression coping spacer.

Once the lab putty had set, the suction tubes were removed and the putty was contoured using a scalpel blade. The 2mm acrylic spacer with 3 windows for special tray stops was then placed on the Master Model. A layer of Vaseline was then placed on both the acrylic spacer and the putty spacers to reduce adhesion of the special tray material to those structures (fig 3.6).

Figure 0.6 Impression coping spacer and base spacer.

Ten special trays were then constructed by a single operator using the same batch of light-cured material under controlled conditions. They were standardised in their dimensions and features, each with 3 stops to ensure that the correct stability and spacing was present when placing the tray on the master model and windows for exposure of the impression transfer copings and their guide pins (fig. 3.7). Each tray was numbered with a black permanent marker to facilitate seamless sequencing when removing the impression from the individual models, as well as to distinguish between the two pouring methods and storage conditions as each individual number had a specific pouring method and storage condition assigned to it.

Figure 0.7 Special tray on Master Model

Before each impression was taken, the master model was prepared by placing an impression coping with its guide pin carefully and firmly in each of the four implant sockets (fig 3.8). This was done by a single operator, for all 20 impressions, to ensure uniformity and decrease operator error.

Figure 0.8 Pre-impression Master Model preparation with 4 impression copings.

The sequencing for impression taking and model pouring followed a very strict protocol as can be seen in the attached pouring sequence data table (Appendix D). Special trays, numbered 1-10 for the first pouring method, and 11-20 for the second pouring method, were placed alongside one another ready for impression taking. One after the other, at 15-minute intervals, starting with Special tray number 1, *Impregum*™ was dispensed by the same operator using the *Pentamix*™ machine into the special tray and the impression of the MM was taken. The impression was left to set for 10 minutes on the MM before removing it in order to ensure adequate set. Before removing it from the master model, the guide pins were carefully unscrewed and removed and the excess impression material was carefully removed using a scalpel blade. The remaining 5 minutes of the 15-minute impression-taking interval was used to carefully remove the impression from the master model and check its fitting surface for voids, and if found satisfactory, was prepared for pouring, this again performed by a single operator (fig 3.9). The Master Model was then cleaned and prepared for the next impression in the sequence and the impression was taken exactly 15 minutes after the previous one. The taking of the next impression also signified the beginning of the 15-minute waiting period for the previous impression before pouring gypsum into it, as per the manufacturer's instructions.

Figure 0.9 Impregum impression fitting surface.

The implants were placed one by one by a single operator (fig 3.10), and the impressions were then boxed and poured.

Figure 0.10 Impression preparation with implants pre-boxing.

Once each model in the conventional pouring method group (1-10) had been poured with gypsum in sequence and left to set for 2.5 hours after its associated pouring time, its specific special tray and impression was then removed, cleaned and prepared to be re-used for the final ten impressions (11-20) of the two-step pouring method group.

In order to standardise the processes of mixing, pouring and storing of the casts, two members of the Wits University laboratory staff responsible for pouring implant casts, were recruited. This allowed one person to mix gypsum, one person to pour it, and one person to prepare the impressions for pouring.

The Type IV gypsum mix was standardised under strictly controlled conditions using the *Whip Mix® Aquaspense SL*™ mechanical dispenser, with a custom set programme created according to the manufacturer's correct WPR instructions in order to decrease the amount of operator error.

The same single batch of type IV gypsum (the same lot number), maintained in a strictly controlled environment as guided by the manufacturer's instructions, was used for all 20 experiments. In order to standardise the mix of the gypsum, the WhipMix® VPM2™ mechanical mixer was used for the mixing of each batch of gypsum, set at a standard mixing speed of 240 rpm for 30 seconds

Ten of the models (1-10) were poured using the conventional method of pouring, which entailed slowly pouring the gypsum mix into a boxed impression with the aid of a vibrator, to minimise air bubbles (fig 3.11).

Figure 0.11 Conventional pouring method (normal), impression un-boxed.

The remaining 10 models were poured using an alternative method (cylinder). This entailed placing evenly cut high-volume saliva ejector tube pieces (roughly 2cms in length) around each implant analogue in order to isolate them from their surroundings (fig 3.12).

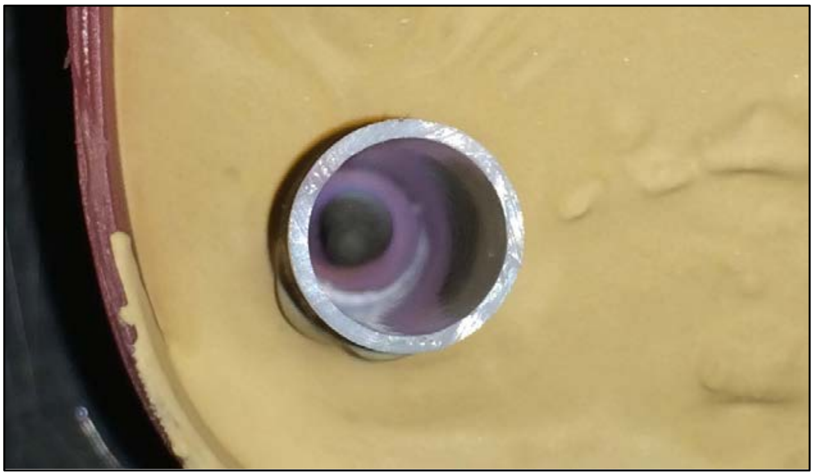

Figure 0.12 Cylinder for cylinder pouring technique.

It was found that the circumference of the cylinder tube was an important factor in allowing a certain volume of gypsum to reach the implant during the second pour. To allow for the exothermic reaction of setting to occur (and therefore not influence the setting time of the second pour), the cast was left for 60 minutes on the lab shelf after the first pour. After this time the tubes were removed and the second pour was fed into the holes using a syringe injection technique with a customised syringe tip (figs 3.13 and 14). When testing this method as described by Rodrigues et al. (2012), multiple voids occurred because the gypsum material set faster than our ability to introduce it smoothly into the hole, a problem similarly reported by Rodrigues et al. (2012). Therefore a customised syringe tip was devised, which had a diameter and length that enabled a faster air-free passage of gypsum directly to the base of the implant, eliminating voids.

Figure 0.13 Adapted syringe for cylinder technique.

Figure 0.14 Injection of gypsum during cylinder technique**.**

Ten of the models, five from each pouring method, were randomly selected (randomisation was done by computer) and these ten randomly chosen casts were placed in individual sealed *Ziploc*™ plastic bags immediately after pouring and left for 24 hours from the time of pouring to ensure an environment of as close to 100% humidity as possible.

Each model was left to set for 2.5 hours before removing it from its impression and trimming off the excess plaster. The temperature and humidity of the plaster room was measured and recorded every hour during the pouring of the impressions in order to ensure the best possible standardised environment. The times of impression taking, pouring and removal of the impression were also carefully monitored and recorded.

Each resultant cast was then placed on the Reflex Microscope and using the Reflex software, the 3D position of each of the implants was recorded (fig 3.15).

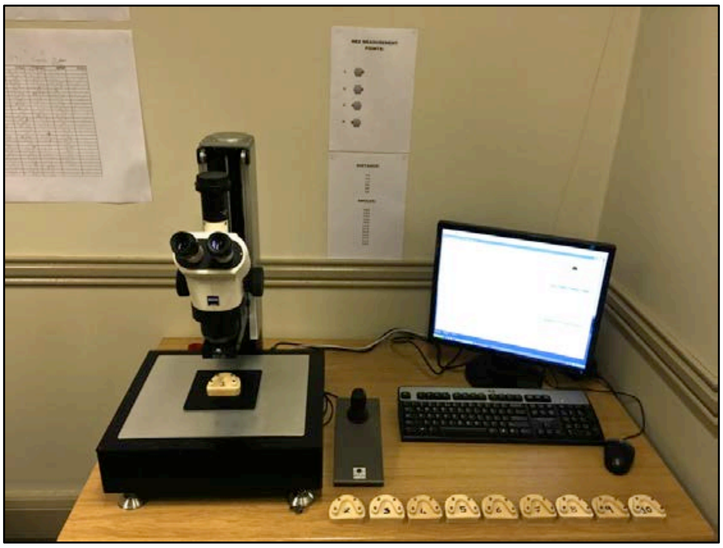

Figure 0.15 Reflex microscope work station.

An individual hex point (fig 3.16) was chosen for each of the 4 implants (fig 3.17) by positioning the light spot observed in the field of view at a tangent to the outermost edge of the top corners of the implant analogue. This point remained as the reference point for that specific number implant and cast throughout the 90-day duration of the study. A single operator took all measurements over the duration of the study.

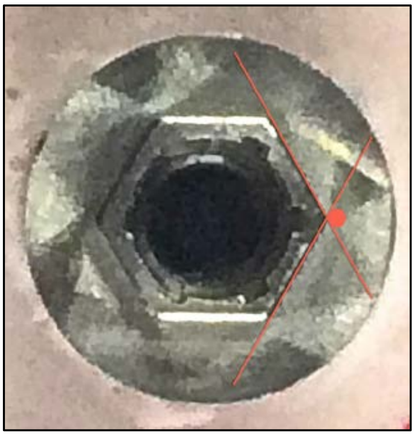

Figure 0.16 Single hex point measurement.

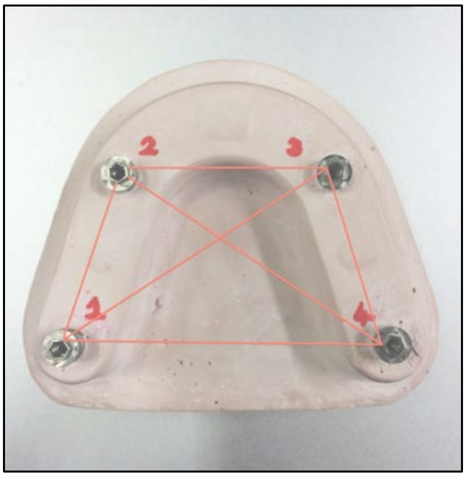

Figure 0.17 Model with four implants and measuring points

The Reflex microscope records each point in space as a coordinate, so that two- and three-dimensional measurements can be calculated for distances as well as for angles. It is accurate to 4 µm. For example, the distance between each of the analogues results in 12 individual distance measurements for each cast, namely distance 1-2, 1-3, 1-4, 2-3, 2-4 and 3-4 (fig 3.17) in a linear plane as well as taking into account height differences.

All 20 casts were then placed on a shelf in the Wits School of Oral Health Sciences which was similar in temperature and humidity to the laboratory in which the casts were poured. The reason the casts were not stored in the laboratory was in order to keep them in a protected environment, as well as for them to be in close proximity to the Reflex microscope in order to decrease factors such as the need for transportation of the casts, the time taken to transport them, as well as temperature and humidity fluctuations during their transportation.

In order to map any distortion over time, every 2-3 weeks, starting from day 1 and ending on day 90, all 6 distances for all 20 casts were measured, in the same way, by the same operator using the same Reflex microscope. The temperature and humidity of the storage environment was also measured and recorded on the same day and time the casts were measured, with the aid of a digital thermometer and hygrometer. The date, time, temperature and humidity during the measurement of each of the 20 casts over the 90-day period were also recorded.

3.3. Sample size

As there were no known studies testing the hypothesis, it was assumed that any distortion of differences greater than 150 µm (0.15mm) would be significant clinically. Using a typical standard deviation of 0.04 µm (Hoods-Moonsammy et al., 2014) yielded a large effect size (d=3750) (Buchner et al., 2009) for which a very small sample size would be required; therefore it was decided that a sample size of 5 replicates per experiment would be used.

3.4. Statistical Analysis

Descriptive analyses were performed for each outcome and their distribution analysed. A two-factor Analysis of Variance (ANOVA) with interaction was used to determine the effect of Method, Storage, and the Method-Storage interaction, on the outcome. Post-hoc tests were carried out using the Tukey-Kramer adjustment for unequal group sizes (to allow for the deletion of outliers), and effect sizes were expressed using Cohen’s d. A one-sample t-test was used to compare mean changes of distances to a change of greater or lesser than 0.15 mm.

Data analysis was carried out using SAS version 9.4 for Windows. The 5% significance level was used.

RESULTS

The temperature variance over the 90 day period never changed by more than 5°C and the humidity never more than 15%, this change being seen gradually over the 90 days as opposed to any sudden drop.

The changes in dimensions from day one to day ninety for the twenty casts were determined for the four experimental conditions of method (normal / cylinder) and storage in the first 24 hours (100% humidity/average humidity)). Five replicates were carried out for each experiment.

For each cast, 6 linear distances and 12 angles between all implants were measured and for each of these, the changes were recorded as:

- Day 1 measurement – Day 90 measurement for each cast to show change over time
- Day 1 measurement – Master Model (MM) to show change due to pouring method and initial storage method
- Day 90 measurement – Master Model (MM) to show change of each cast relative to the master model over time

Univariate statistical analysis revealed some variation, and outliers in the change data, which could be partly explained by the measurements being analysed. For example, the box-and-whisker plot for the distance measurement between fixtures 1 and 2 (see Fig. 3.1) for the main outcome of interest, namely the cast measurement at day 90 relative to the master model is shown in figure 4.1:

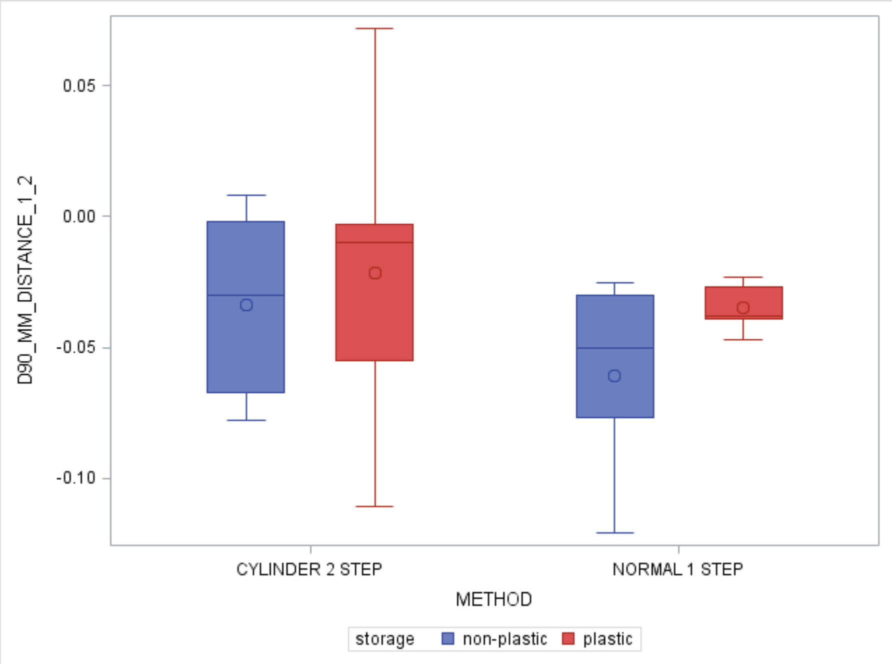

Figure 0.1 Distance change measurement between fixtures 1 and 2 from master model at 90 days

However, the same measurement for distance 1 to 4, which measures across the model, is shown in figure 4.2:

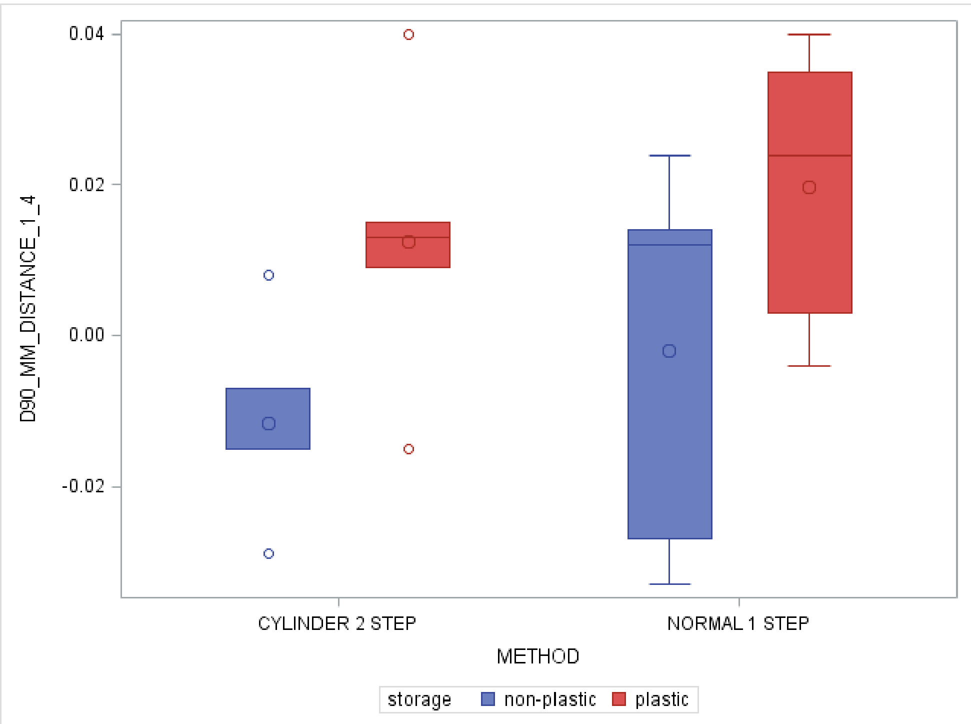

Figure 0.2 Distance change measurement between fixtures 1 and 4 from master model at 90 days

Therefore the effect of such outliers were removed or data transformations applied as necessary for the ANOVA technique, in combination with post-hoc analyses if unequal group sizes resulted. For example, table 4.1 shows initial significant difference for the interaction of pouring methods (1-step vs 2-step) with initial storage conditions (plastic vs non plastic) but post-hoc tests showed no significant differences.

Table 0.1 Initial interaction of method vs storage for the angle between fixtures 2, 1 and 4, for the change between Day 1 and Day 90

D1_90 ANGLE 2-1-4

Source	DF	Type III SS	Mean Square	F Value	Pr > F
METHOD	1	0.0001682	0.0001682	0.16	0.70
storage	1	0.0006498	0.0006498	0.61	0.44
METHOD*storage	1	0.01058	0.01058	10.01	0.006

Very few of the analyses revealed any statistically significant differences in the effects of the pouring method, initial storage in plastic or not, or the method-storage interactions.

For the differences between Day 1 and the Master Model there were no significant effects of Method, Storage, and the Method-Storage interaction, except for Distances 1-3, 1-4, 2-3, and 2-4, where the mean change in distance for plastic storage was higher than that for non-plastic storage. An example is given in Table 4.2 for the difference between fixtures 1 and 3.

Table 0.2 Interaction of method vs storage for the distance between fixtures 1 and 3, for the differences between Day 1 and the Master Model (MM)

D1-MM DISTANCE 1-3 smallest value for normal/plastic removed as outlier (thus n=19)

Source	DF	Type III SS	Mean Square	F Value	Pr > F
METHOD	1	0.0013242	0.00132424	1.53	0.23
storage	1	0.0048113	0.0048113	5.57	0.032
METHOD*storage	1	0.0003624	0.00036236	0.42	0.53

When the method vs storage interaction was removed, storage remained significant (Table 4.3).

Table 0.3 Storage method remained significant

Source	DF	Type III SS	Mean Square	F Value	Pr > F
METHOD	1	0.0012483	0.00124832	1.5	0.24
storage	1	0.0046734	0.00467338	5.62	0.031

The Least-Squares (estimated) means showed that the mean change in distance for the plastic storage method (0.133, 95% CI ±0.020 mm) was higher than that for the non-plastic method (0.102, 95% CI ± 0.019 mm). The effect size was large (Cohen's d=1.1) and both changes were significantly greater than 0. However, the differences did not exceed 0.15 mm. Similar results were obtained for the distances 1-4, 2-3, and 2-4.

For the differences between the casts on Day 1 and Day 90, there were no significant effects of the outcomes except for two of the angles (1-2-3 and 2-1-3) but these changes did not correlate with the corresponding distances making up these angles. For the first angle, the mean change was higher for the 2-step cylinder method (least squares mean 0.044, 95% CI

±0.037 vs 0.013, 95% CI ±0.033) and for the second, the higher change was for the one-step, non-plastic method (least squares mean -0.009, 95% CI ±0.019 vs -0.050, 95% CI ±0.021).

For both of these the effect size was large, but again, no differences resulted in the mean of the distances forming these angles of greater than 0.15 mm. However, there were some distance measures that did display such a differences, which will be shown later.

For the differences between Day 90 and the Master Model there were also no significant effects of the outcomes, except for distances 1-4, and 2-3, where the mean change in distance for plastic storage was higher than that for non-plastic storage (Tables 4.4 and 4.5).

Table 0.4 Interaction of method vs storage for the distance between fixtures 1 and 4, for the differences between Day 90 and the Master Model (MM)

D90-MM DISTANCE 1-4

Source	DF	Type III SS	Mean Square	F Value	Pr > F
METHOD	1	0.0003528	0.0003528	0.87	0.36
storage	1	0.0025992	0.0025992	6.42	0.022
METHOD*storage	1	0.0000072	0.0000072	0.02	0.90

Source	DF	Type III SS	Mean Square	F Value	Pr > F
METHOD	1	0.0003528	0.0003528	0.92	0.35
storage	1	0.0025992	0.0025992	6.81	0.018

storage	LSMEAN	95% CI	Cohen's d
non-plastic	-0.007	0.013	1.2 (large)
plastic	0.016	0.013	

Table 0.5 Interaction of method vs storage for the distance between fixtures 2 and 3, for the differences between Day 90 and the Master Model (MM)

D90-MM DISTANCE 1-4

Source	DF	Type III SS	Mean Square	F Value	Pr > F
METHOD	1	0.0002048	0.0002048	0.52	0.48
storage	1	0.002645	0.002645	6.74	0.020
METHOD*storage	1	0.0002178	0.0002178	0.55	0.47

Source	DF	Type III SS	Mean Square	F Value	Pr > F
METHOD	1	0.0002048	0.0002048	0.54	0.47
storage	1	0.002645	0.002645	6.92	0.018

storage	LSMEAN	95% CI	Cohen's d
non-plastic	0.052	0.013	1.3 (large)
plastic	0.075	0.013	

For the tests for any mean changes in distances that would be greater or lesser than 0.15 mm, no significant differences were found, although some individual changes were found, as shown in Table 4.6.

Table 0.6 Individual distances showing a change of greater or lesser than 0.15 mm. Red signifies expansion, green contraction.

MODEL NUMBER	METHOD	storage	D1-MM DISTANCE 1-3	D1-MM DISTANCE 2-4	D1 MM DISTANCE 3-4	D90-MM DISTANCE 2-4	D90-MM DISTANCE 3-4
1	NORMAL 1 STEP	non-plastic	0.153	0.023	0.068	-0.033	0.018
2	NORMAL 1 STEP	plastic	0.047	-0.019	-0.079	-0.014	-0.057
3	NORMAL 1 STEP	non-plastic	0.060	-0.179	-0.263	-0.226	-0.298
4	NORMAL 1 STEP	plastic	0.143	0.045	0.115	0.001	0.064
5	NORMAL 1 STEP	non-plastic	0.131	-0.115	0.031	-0.113	0.015
6	NORMAL 1 STEP	plastic	0.151	-0.036	0.050	-0.078	0.026
7	NORMAL 1 STEP	plastic	0.169	-0.003	0.083	-0.011	0.070
8	NORMAL 1 STEP	non-plastic	0.074	-0.032	0.094	-0.043	0.061
9	NORMAL 1 STEP	plastic	0.124	0.016	0.078	0.016	0.053
10	NORMAL 1 STEP	non-plastic	0.112	-0.017	0.043	-0.041	0.014
11	CYLINDER 2 STEP	plastic	0.145	-0.029	0.057	-0.044	0.037
12	CYLINDER 2 STEP	plastic	0.141	-0.032	0.040	-0.079	-0.022
13	CYLINDER 2 STEP	non-plastic	0.071	-0.018	-0.063	-0.036	0.020
14	CYLINDER 2 STEP	non-plastic	0.137	-0.042	0.065	-0.035	0.072
15	CYLINDER 2 STEP	plastic	0.083	0.020	0.097	-0.025	0.052
16	CYLINDER 2 STEP	plastic	0.122	0.110	0.102	0.040	0.083
17	CYLINDER 2 STEP	plastic	0.115	0.115	0.079	0.073	0.053
18	CYLINDER 2 STEP	non-plastic	0.089	-0.037	0.094	-0.015	0.078
19	CYLINDER 2 STEP	non-plastic	0.073	0.005	0.056	-0.030	0.008
20	CYLINDER 2 STEP	non-plastic	0.120	-0.014	0.111	-0.035	0.065

DISCUSSION

This study sought to determine whether or not a specific pouring method or storage condition would prove to be superior over the other with respect to minimising or eliminating distortion in gypsum models. The literature review described studies which elaborated on the behaviour of gypsum in different temperatures and environments as well as described guidelines on how gypsum should be stored and mixed. This information was used to structure this study which sought to answer questions yet unanswered about gypsum behaviour. Although there were few studies with which to compare the results, the information received from previous gypsum studies provided the foundation for the methods used here.

The first outcome measure compared the two different pouring methods to one another and the second compared the two different 24-hour storage conditions to one another. The 20 casts and their results over the 90 day period were then all individually compared with the original Master Model values.

The outcome Day 1 - Master Model revealed 4 individual distances where the mean change for humid storage was higher than that of normal storage such as shown in table 4.2. The higher change in distances in these four measurements may have been due to the fact that when casts set in an environment of 100% humidity, there is always moisture available in the air surrounding the cast, which reduces the initial setting contraction and contributes to creating an environment favouring longer crystal growth resulting in increased levels of expansion (Santos and Ballester, 1984). The results, however, were inconsistent and thus rendered the distortion unpredictable, and as a result unreliable. Therefore there seems to be no benefit in allowing the gypsum to set in 100% humidity.

Although there were no statistically significant differences in the overall mean values under all conditions, there were some conditions under which an effect size was observed.

In the outcome Day 1 - Day 90, in two specific angles, 1-2-3 and angle 2-1-3. Angle 1-2-3 showed a significance of method (p=0.022) for the cylinder technique and its significance remained (p=0.026) even after removal of the Method-storage interaction term. Angle 2-1-3 showed significance in its method-storage interaction (p=0.029), the mean change in angle for the cylinder/normal method being lower than that for the normal/humid method. Inspection of the confidence intervals for these results showed that the cylinder method revealed increased contraction of the angle but that there was no significant change from 0 for the normal method. The differences in both cases did not exceed the clinically significant value of 0.15 mm.

For the outcome, Day 90 - Master Model, only two distances, 1-4 and 1-2 showed significant mean changes in distances for humid storage compared with normal storage: this could again be attributed to the principle of hygroscopic expansion mentioned above.

Model storage over time is an important consideration when considering future replacement of expensive componentry used in implant dentistry. Implant superstructures may fracture over time, and if a new superstructure can be made using the original casts, considerable time and component costs can be saved. From a clinical viewpoint, a discrepancy of fit of more than 0.15mm has been used as a benchmark (Jemt, 1991). In this study there were no measurements that were found to have both a statistical and clinical impact; however, there were individual distances where some changes observed were greater than 0.15mm and less than -0.15mm (Table 4.6). This occurred in only four of the casts, and highlights the reality that however thorough and controlled the clinical and laboratory techniques may be, there is always a possibility for some distortion. This may account for the occasional lack of passive fit of implant superstructure frameworks, although there are other variables in addition to that of cast distortion, such as the impression procedures and materials themselves (Hoods-Moonsammy et al., 2014). Overall, though, within the limitations of this study and the time frame used, it is likely that under controlled conditions, there will be clinically insignificant consequences of re-using casts stored under normal conditions of temperature and humidity.

CONCLUSIONS AND RECOMMENDATIONS

Within the limitations of this study, the following conclusions can be made:

The null hypothesis is confirmed in that there is no clinically significant difference between the storage conditions or the pouring methods used in this study.

It is important, however, to control the measuring and mixing of gypsum but to be aware that even under strictly controlled situations, it is still possible to incur occasional levels of distortion. Factors such as mixing time and speed should all preferably be kept constant by using automatic mixers and dispensers as this ensures a repeatable uniform mix, and room temperature water for mixing of the gypsum is sufficient.

There is no benefit or need to employ the two-step cylinder technique of pouring as the one-step conventional method is sufficient and in fact saves the operator time and cost.

Storage of type IV gypsum casts in a humid environment for the 1st 24 hours is unnecessary, both in terms of time and cost.

This study has reported on the shelf storage of casts for a period of 90 days and it can be safely recommended that undamaged casts can be stored in a dental practice or lab environment and re-used for repair of frameworks for a period of up to 90 days. The casts will continue to be stored and will be measured at intervals greater than this, and the results will be reported in a future publication.

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APPENDIX A: ETHICS WAIVER CERTIFICATE

Human Research Ethics Committee (Medical)

Research Office Secretariat: Senate House Room SH10005, 10th floor. Tel +27 (0)11-717-1252
Medical School Secretariat: P V Tobias Building, Room 304, 3rd floor Tel +27 (0)11-717-2700
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UNIVERSITY OF THE WITWATERSRAND JOHANNESBURG

Ref: W-CJ-140725-1 25/07/2014

TO WHOM IT MAY CONCERN:

Waiver: This certifies that the following research does not require clearance from the Human Research Ethics Committee (Medical).

Investigator: **Prof C P Owen.**

Project title: **The effect of pouring method and storage conditions on dental implant model distortion.**

Reason: This is a laboratory study on dental materials. There are no human participants

UNIVERSITY OF THE WITWATERSRAND
PROF PE CLEATON-JONES
HREC (MEDICAL)
2014 -07- 25
JOHANNESBURG

Professor Peter Cleaton-Jones

Chair: Human Research Ethics Committee (Medical)

Copy - HREC(Medical) Secretariat : Anisa Keshav, Zanele Ndlovu.

APPENDIX B: DATA TABLES

Storage condition comparison

storage	Variable	N Obs	Mean	Std Dev	Median	Interquartile range		Minimum	Maximum
Non-Plastic	**D1_MM_DISTANCE_1_3**	10	0,102	0,033	0,101	0,073	0,131	0,060	0,153
	D1_MM_DISTANCE_1_4	10	0,007	0,022	0,002	-0,006	0,031	-0,024	0,043
	D1_MM_DISTANCE_2_3	10	0,057	0,031	0,057	0,038	0,085	0,007	0,102
	D1_MM_DISTANCE_2_4	10	-0,043	0,060	-0,025	-0,042	-0,014	-0,179	0,023
Plastic	**D1_MM_DISTANCE_1_3**	10	0,124	0,036	0,133	0,115	0,145	0,047	0,169
	D1_MM_DISTANCE_1_4	10	0,037	0,016	0,039	0,026	0,048	0,010	0,059
	D1_MM_DISTANCE_2_3	10	0,086	0,017	0,086	0,076	0,100	0,060	0,108
	D1_MM_DISTANCE_2_4	10	0,019	0,056	0,007	-0,029	0,045	-0,036	0,115

Pouring method comparison

Method	Variable	N Obs	Mean	Std Dev	Median	Interquartile range		Minimum	Maximum
Cyinder	**D1_MM_DISTANCE_1_3**	10	0,110	0,028	0,118	0,083	0,137	0,071	0,145
	D1_MM_DISTANCE_1_4	10	0,026	0,023	0,029	0,007	0,046	-0,006	0,059
	D1_MM_DISTANCE_2_3	10	0,071	0,028	0,078	0,058	0,085	0,016	0,108
	D1_MM_DISTANCE_2_4	10	0,008	0,058	-0,016	-0,032	0,020	-0,042	0,115
Normal	**D1_MM_DISTANCE_1_3**	10	0,116	0,042	0,128	0,074	0,151	0,047	0,169
	D1_MM_DISTANCE_1_4	10	0,019	0,026	0,027	-0,005	0,038	-0,024	0,055
	D1_MM_DISTANCE_2_3	10	0,073	0,031	0,083	0,055	0,095	0,007	0,108
	D1_MM_DISTANCE_2_4	10	-0,032	0,067	-0,018	-0,036	0,016	-0,179	0,045

Individual groups of 5 (cylinder pouring)

Method	Storage	Variable	N Obs	Mean	Std Dev	Median	Interquartile range		Minimum	Maximum
Cylinder	Non Plastic	**D1_MM_DISTANCE_1_3**	5	0,098	0,029	0,089	0,073	0,120	0,071	0,137
		D1_MM_DISTANCE_1_4	5	0,008	0,016	0,007	-0,003	0,009	-0,006	0,035
		D1_MM_DISTANCE_2_3	5	0,055	0,029	0,058	0,038	0,079	0,016	0,085
		D1_MM_DISTANCE_2_4	5	-0,021	0,019	-0,018	-0,037	-0,014	-0,042	0,005
	Plastic	**D1_MM_DISTANCE_1_3**	5	0,121	0,025	0,122	0,115	0,141	0,083	0,145
		D1_MM_DISTANCE_1_4	5	0,043	0,014	0,046	0,039	0,048	0,022	0,059
		D1_MM_DISTANCE_2_3	5	0,086	0,018	0,085	0,076	0,100	0,063	0,108
		D1_MM_DISTANCE_2_4	5	0,037	0,072	0,020	-0,029	0,110	-0,032	0,115

Individual groups of 5 (normal pouring)

Method	Storage	Variable	N Obs	Mean	Std Dev	Median	Interquartile range		Minimum	Maximum
Normal	Non Plastic	**D1_MM_DISTANCE_1_3**	5	0,106	0,039	0,112	0,074	0,131	0,060	0,153
		D1_MM_DISTANCE_1_4	5	0,006	0,029	-0,005	-0,015	0,031	-0,024	0,043
		D1_MM_DISTANCE_2_3	5	0,059	0,037	0,055	0,047	0,086	0,007	0,102
		D1_MM_DISTANCE_2_4	5	-0,064	0,082	-0,032	-0,115	-0,017	-0,179	0,023
	Plastic	**D1_MM_DISTANCE_1_3**	5	0,127	0,047	0,143	0,124	0,151	0,047	0,169
		D1_MM_DISTANCE_1_4	5	0,031	0,017	0,028	0,026	0,038	0,010	0,055
		D1_MM_DISTANCE_2_3	5	0,086	0,018	0,086	0,079	0,095	0,060	0,108
		D1_MM_DISTANCE_2_4	5	0,001	0,031	-0,003	-0,019	0,016	-0,036	0,045

APPENDIX C: FULL DATA SET

MODEL NUMBER	METHOD	storage	D1_90 DISTANCE 1-2	D1_90 DISTANCE 1-3	D1_90 DISTANCE 1-4	D1_90 DISTANCE 2-3	D1_90 DISTANCE 2-4	D1_90 DISTANCE 3-4	D1_90 ANGLE 1-2-3	D1_90 ANGLE 1-2-4	D1_90 ANGLE 1-3-2	D1_90 ANGLE 1-3-4	D1_90 ANGLE 1-4-2	D1_90 ANGLE 1-4-3	D1_90 ANGLE 2-1-3	D1_90 ANGLE 2-1-4	D1_90 ANGLE 2-3-4	D1_90 ANGLE 2-4-3	D1_90 ANGLE 3-1-4	D1_90 ANGLE 3-2-4
1	NORMAL 1 STEP	non-plastic	0.038	0.047	0.029	0.031	0.056	0.050	-0.029	-0.067	0.021	-0.060	0.018	0.021	0.009	0.049	-0.036	0.002	0.039	0.035
2	NORMAL 1 STEP	plastic	-0.004	-0.006	0.014	-0.007	-0.005	-0.022	0.009	0.047	-0.002	0.064	-0.010	-0.029	-0.006	-0.038	0.068	-0.023	-0.036	-0.045
3	NORMAL 1 STEP	non-plastic	0.059	0.061	0.012	0.037	0.047	0.035	-0.059	-0.109	0.048	-0.123	0.060	0.103	0.010	0.048	-0.046	0.025	0.020	0.022
4	NORMAL 1 STEP	plastic	0.030	0.056	0.052	0.022	0.044	0.051	0.051	0.017	-0.016	-0.023	0.002	-0.006	-0.035	-0.020	-0.058	0.005	0.029	0.054
5	NORMAL 1 STEP	non-plastic	0.019	0.026	0.009	-0.001	-0.002	0.016	0.047	0.013	-0.005	-0.042	0.023	0.034	-0.042	-0.036	-0.050	0.013	0.007	0.037
6	NORMAL 1 STEP	plastic	0.052	0.007	0.026	-0.014	0.042	0.024	-0.080	-0.059	0.092	0.031	0.045	-0.050	-0.012	0.014	0.133	-0.101	0.019	-0.031
7	NORMAL 1 STEP	plastic	0.045	0.045	-0.002	0.019	0.008	0.013	-0.024	-0.054	0.035	-0.105	0.062	0.104	-0.011	-0.007	-0.068	0.040	0.001	0.028
8	NORMAL 1 STEP	non-plastic	0.021	-0.016	-0.029	-0.018	0.011	0.033	-0.064	-0.106	0.062	-0.062	0.036	-0.006	0.002	0.070	0.002	-0.043	0.067	0.041
9	NORMAL 1 STEP	plastic	0.001	0.006	-0.007	0.001	0.000	0.025	0.018	-0.018	-0.010	-0.049	0.004	0.013	-0.009	0.015	-0.077	0.021	0.036	0.056
10	NORMAL 1 STEP	non-plastic	0.017	0.004	0.019	-0.011	0.024	0.029	0.001	-0.012	0.023	0.017	0.005	-0.048	-0.023	0.006	0.038	-0.052	0.030	0.014
11	CYLINDER 2 STEP	plastic	-0.022	0.023	0.022	0.022	0.015	0.020	0.083	0.039	-0.074	-0.008	-0.047	-0.002	-0.008	0.008	-0.072	0.039	0.009	0.033
12	CYLINDER 2 STEP	plastic	0.019	0.028	0.031	0.005	0.047	0.062	0.036	-0.029	-0.005	-0.026	-0.007	-0.038	-0.031	0.036	-0.025	-0.034	0.063	0.060
13	CYLINDER 2 STEP	non-plastic	0.002	-0.011	0.024	0.037	0.018	-0.083	-0.159	0.019	0.048	0.142	-0.015	-0.016	0.111	-0.006	0.203	-0.011	-0.125	-0.192
14	CYLINDER 2 STEP	non-plastic	-0.016	0.007	0.022	-0.002	-0.007	-0.007	0.078	0.078	-0.050	0.045	-0.030	-0.022	-0.028	-0.048	-0.001	0.006	-0.022	-0.005
15	CYLINDER 2 STEP	plastic	0.035	0.042	0.039	0.018	0.045	0.045	0.001	-0.020	0.015	-0.022	0.015	-0.007	-0.016	0.005	-0.017	-0.015	0.029	0.032
16	CYLINDER 2 STEP	plastic	0.066	0.024	0.019	0.031	0.070	0.019	-0.200	-0.141	0.125	-0.016	0.056	0.005	0.075	0.084	0.109	-0.050	0.009	-0.059
17	CYLINDER 2 STEP	plastic	0.021	0.016	0.026	0.014	0.042	0.026	-0.044	-0.033	0.027	0.012	0.001	-0.031	0.017	0.032	0.035	-0.030	0.019	-0.007
18	CYLINDER 2 STEP	non-plastic	0.004	0.013	0.001	-0.023	-0.022	0.016	0.109	0.044	-0.029	-0.033	0.014	0.016	-0.079	-0.058	-0.058	-0.001	0.018	0.059
19	CYLINDER 2 STEP	non-plastic	0.024	0.025	0.026	0.001	0.035	0.048	0.022	-0.024	0.009	-0.023	0.008	-0.023	-0.032	0.016	-0.011	-0.033	0.046	0.044
20	CYLINDER 2 STEP	non-plastic	0.031	0.045	0.027	0.003	0.021	0.046	0.069	0.021	-0.008	-0.059	0.024	0.024	-0.061	-0.026	-0.066	-0.001	0.035	0.067

MODEL NUMBER	METHOD	storage	D1_MM DISTANCE 1-2	D1_MM DISTANCE 1-3	D1_MM DISTANCE 1-4	D1_MM DISTANCE 2-3	D1_MM DISTANCE 2-4	D1_MM DISTANCE 3-4	D1_MM ANGLE 1-2-3	D1_MM ANGLE 1-2-4	D1_MM ANGLE 1-3-2	D1_MM ANGLE 1-3-4	D1_MM ANGLE 1-4-2	D1_MM ANGLE 1-4-3	D1_MM ANGLE 2-1-3	D1_MM ANGLE 2-1-4	D1_MM ANGLE 2-3-4	D1_MM ANGLE 2-4-3	D1_MM ANGLE 3-1-4	D1_MM ANGLE 3-2-4
1	NORMAL 1 STEP	non-plastic	0.008	0.153	0.043	0.102	0.023	0.068	0.234	0.054	-0.183	-0.250	-0.017	0.234	-0.050	-0.036	-0.436	0.253	0.016	0.183
2	NORMAL 1 STEP	plastic	-0.031	0.047	0.010	0.086	-0.019	-0.079	-0.001	0.084	-0.095	-0.009	-0.041	0.146	0.096	-0.042	-0.106	0.188	-0.137	-0.082
3	NORMAL 1 STEP	non-plastic	-0.062	0.060	-0.015	0.086	-0.179	-0.263	0.138	0.364	-0.186	0.040	-0.007	0.355	0.048	-0.357	-0.160	0.371	-0.395	-0.211
4	NORMAL 1 STEP	plastic	-0.008	0.143	0.055	0.095	0.045	0.115	0.263	0.050	-0.206	-0.237	-0.055	0.154	-0.057	0.005	-0.473	0.229	0.083	0.245
5	NORMAL 1 STEP	non-plastic	-0.058	0.131	-0.024	0.047	-0.115	0.031	0.511	0.214	-0.326	-0.341	-0.025	0.339	-0.185	-0.188	-0.674	0.369	0.001	0.305
6	NORMAL 1 STEP	plastic	0.013	0.151	0.026	0.060	-0.036	0.050	0.340	0.124	-0.196	-0.276	0.022	0.278	-0.143	-0.145	-0.473	0.256	-0.002	0.217
7	NORMAL 1 STEP	plastic	0.022	0.169	0.038	0.079	-0.003	0.083	0.320	0.083	-0.194	-0.306	0.016	0.273	-0.126	-0.098	-0.508	0.262	0.033	0.246
8	NORMAL 1 STEP	non-plastic	-0.029	0.074	-0.005	0.007	-0.032	0.094	0.338	0.073	-0.189	-0.229	-0.027	0.122	-0.149	-0.045	-0.423	0.152	0.107	0.271
9	NORMAL 1 STEP	plastic	-0.046	0.124	0.028	0.108	0.016	0.078	0.264	0.068	-0.249	-0.237	-0.085	0.189	-0.016	0.018	-0.508	0.288	0.048	0.220
10	NORMAL 1 STEP	non-plastic	-0.008	0.112	0.031	0.055	-0.017	0.043	0.269	0.115	-0.176	-0.179	-0.018	0.177	-0.092	-0.097	-0.365	0.201	0.001	0.164
11	CYLINDER 2 STEP	plastic	-0.025	0.145	0.022	0.085	-0.029	0.057	0.351	0.129	-0.252	-0.278	-0.033	0.265	-0.098	-0.095	-0.545	0.308	0.012	0.237
12	CYLINDER 2 STEP	plastic	-0.036	0.141	0.046	0.076	-0.032	0.040	0.398	0.202	-0.277	-0.199	-0.058	0.219	-0.121	-0.143	-0.477	0.279	-0.021	0.199
13	CYLINDER 2 STEP	non-plastic	0.000	0.071	0.009	0.085	-0.018	-0.063	0.005	0.058	-0.069	-0.071	0.003	0.196	0.065	-0.061	-0.143	0.194	-0.124	-0.051
14	CYLINDER 2 STEP	non-plastic	-0.008	0.137	0.007	0.058	-0.042	0.065	0.355	0.106	-0.220	-0.305	0.002	0.271	-0.135	-0.107	-0.534	0.275	0.034	0.259
15	CYLINDER 2 STEP	plastic	-0.076	0.083	0.048	0.063	0.020	0.097	0.338	0.132	-0.273	-0.121	-0.137	0.037	-0.065	0.006	-0.411	0.186	0.083	0.225
16	CYLINDER 2 STEP	plastic	0.056	0.122	0.059	0.100	0.110	0.102	-0.017	-0.116	-0.024	-0.176	0.007	0.105	0.041	0.109	-0.203	0.100	0.070	0.103
17	CYLINDER 2 STEP	plastic	0.093	0.115	0.039	0.108	0.115	0.079	-0.173	-0.198	0.075	-0.193	0.067	0.144	0.098	0.132	-0.140	0.091	0.049	0.048
18	CYLINDER 2 STEP	non-plastic	-0.063	0.089	-0.006	0.038	-0.037	0.094	0.400	0.104	-0.271	-0.261	-0.073	0.160	-0.128	-0.030	-0.537	0.236	0.101	0.301
19	CYLINDER 2 STEP	non-plastic	-0.054	0.073	-0.003	0.079	0.005	0.056	0.189	0.022	-0.197	-0.195	-0.078	0.144	0.008	0.057	-0.395	0.224	0.051	0.171
20	CYLINDER 2 STEP	non-plastic	0.001	0.120	0.035	0.016	-0.014	0.111	0.393	0.132	-0.197	-0.237	-0.008	0.143	-0.196	-0.104	-0.436	0.152	0.094	0.284

MODEL NUMBER	METHOD	storage	D90_MM DISTANCE 1-2	D90_MM DISTANCE 1-3	D90_MM DISTANCE 1-4	D90_MM DISTANCE 2-3	D90_MM DISTANCE 2-4	D90_MM _DISTANC E 3-4	D90_MM ANGLE 1-2-3	D90_MM ANGLE 1-2-4	D90_MM ANGLE 1-3-2	D90_MM ANGLE 1-3-4	D90_MM ANGLE 1-4-2	D90_MM ANGLE 1-4-3	D90_MM ANGLE 2-1-3	D90_MM ANGLE 2-1-4	D90_MM ANGLE 2-3-4	D90_MM ANGLE 2-4-3	D90_MM ANGLE 3-1-4	D90_MM ANGLE 3-2-4
1	NORMAL 1 STEP	non-plastic	-0.030	0.106	0.014	0.071	-0.033	0.018	0.263	0.121	-0.204	-0.190	-0.035	0.213	-0.059	-0.085	-0.400	0.251	-0.023	0.148
2	NORMAL 1 STEP	plastic	-0.027	0.053	-0.004	0.093	-0.014	-0.057	-0.010	0.037	-0.093	-0.073	-0.031	0.175	0.102	-0.004	-0.174	0.211	-0.101	-0.037
3	NORMAL 1 STEP	non-plastic	-0.121	-0.001	-0.027	0.049	-0.226	-0.298	0.197	0.473	-0.234	0.163	-0.067	0.252	0.038	-0.405	-0.114	0.346	-0.415	-0.233
4	NORMAL 1 STEP	plastic	-0.038	0.087	0.003	0.073	0.001	0.064	0.212	0.033	-0.190	-0.214	-0.057	0.160	-0.022	0.025	-0.415	0.224	0.054	0.191
5	NORMAL 1 STEP	non-plastic	-0.077	0.105	-0.033	0.048	-0.113	0.015	0.464	0.201	-0.321	-0.299	-0.048	0.305	-0.143	-0.152	-0.624	0.356	-0.006	0.268
6	NORMAL 1 STEP	plastic	-0.039	0.144	0.024	0.074	-0.078	0.026	0.420	0.183	-0.288	-0.307	-0.023	0.328	-0.131	-0.159	-0.606	0.357	-0.021	0.248
7	NORMAL 1 STEP	plastic	-0.023	0.124	0.040	0.060	-0.011	0.070	0.344	0.137	-0.229	-0.201	-0.046	0.169	-0.115	-0.091	-0.440	0.222	0.032	0.218
8	NORMAL 1 STEP	non-plastic	-0.050	0.090	0.024	0.025	-0.043	0.061	0.402	0.179	-0.251	-0.167	-0.063	0.128	-0.151	-0.115	-0.425	0.195	0.040	0.230
9	NORMAL 1 STEP	plastic	-0.047	0.118	0.035	0.107	0.016	0.053	0.246	0.086	-0.239	-0.188	-0.089	0.176	-0.007	0.003	-0.431	0.267	0.012	0.164
10	NORMAL 1 STEP	non-plastic	-0.025	0.108	0.012	0.066	-0.041	0.014	0.268	0.127	-0.199	-0.196	-0.023	0.225	-0.069	-0.103	-0.403	0.253	-0.029	0.150
11	CYLINDER 2 STEP	plastic	-0.003	0.122	-0.015	0.063	-0.044	0.037	0.268	0.090	-0.178	-0.270	0.014	0.267	-0.090	-0.103	-0.473	0.269	0.003	0.204
12	CYLINDER 2 STEP	plastic	-0.055	0.113	0.015	0.071	-0.079	-0.022	0.362	0.231	-0.272	-0.173	-0.051	0.257	-0.090	-0.179	-0.452	0.313	-0.084	0.139
13	CYLINDER 2 STEP	non-plastic	-0.002	0.082	-0.015	0.048	-0.036	0.020	0.164	0.039	-0.117	-0.213	0.018	0.212	-0.046	-0.055	-0.346	0.205	0.001	0.141
14	CYLINDER 2 STEP	non-plastic	0.008	0.130	-0.015	0.060	-0.035	0.072	0.277	0.028	-0.170	-0.350	0.032	0.293	-0.107	-0.059	-0.533	0.269	0.056	0.264
15	CYLINDER 2 STEP	plastic	-0.111	0.041	0.009	0.045	-0.025	0.052	0.337	0.152	-0.288	-0.099	-0.152	0.044	-0.049	0.001	-0.394	0.201	0.054	0.193
16	CYLINDER 2 STEP	plastic	-0.010	0.098	0.040	0.069	0.040	0.083	0.183	0.025	-0.149	-0.160	-0.049	0.100	-0.034	0.025	-0.312	0.150	0.061	0.162
17	CYLINDER 2 STEP	plastic	0.072	0.099	0.013	0.094	0.073	0.053	-0.129	-0.165	0.048	-0.205	0.066	0.175	0.081	0.100	-0.175	0.121	0.030	0.055
18	CYLINDER 2 STEP	non-plastic	-0.067	0.076	-0.007	0.061	-0.015	0.078	0.291	0.060	-0.242	-0.228	-0.087	0.144	-0.049	0.028	-0.479	0.237	0.083	0.242
19	CYLINDER 2 STEP	non-plastic	-0.078	0.048	-0.029	0.078	-0.030	0.008	0.167	0.046	-0.206	-0.172	-0.086	0.167	0.040	0.041	-0.384	0.257	0.005	0.127
20	CYLINDER 2 STEP	non-plastic	-0.030	0.075	0.008	0.013	-0.035	0.065	0.324	0.111	-0.189	-0.178	-0.032	0.119	-0.135	-0.078	-0.370	0.153	0.059	0.217

APPENDIX D: POURING SEQUENCE DATA TABLE 1-10

05-Aug-15	IMPRESSION 1	IMPRESSION 2	IMPRESSION 3	IMPRESSION 4	IMPRESSION 5	IMPRESSION 6	IMPRESSION 7	IMPRESSION 8	IMPRESSION 9	IMPRESSION 10
TIME TAKEN	9:34	9:45	9:55	10:09	10:25	10:40	10:55	11:10	11:23	11:37
TEMP C	25.5	25.4	25.4	24.4	25.5	25.7	25.7	25.8	25.8	25.9
HUMIDITY %	27	26	26	26	26	26	26	26	26	26
TIME POURED	10:04	10:15	10:25	10:39	10:55	11:10	11:25	11:40	11:53	12:07
TEMP C	25.4	25.4	25.3	25.7	25.7	25.8	25.8	25.9	26.0	26.1
HUMIDITY %	26	26	26	26	26	26	26	26	26	26
REMOVE & TRIM	12:34	12:45	12:55	13:09	13:25	13:40	13:55	14:10	14:23	14:37