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Comparing Volumetric Dimensional Stability and Accuracy of Newly Formulated Polyvinyl Siloxanether, Polyvinyl Siloxane and Polyether Impression Materials Using Micro-Computed Tomography

Yilmaz Umut Aslan, Yasemin Ozkan

Marmara University, Faculty of Dentistry, Department of Prosthodontics, Istanbul, Turkey

Correspondence Author: Yilmaz Umut Aslan
E-mail: umut.aslan@marmara.edu.tr
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ABSTRACT

Objective: The purpose of this study was to compare volumetric dimensional accuracy and stability of polyvinylsiloxane, polyether and new formulated polyvinylsiloxanether impression materials by using micro-computed tomography.

Methods: A total of 42 impressions were made of stainless steel metal dyes. Polyvinylsiloxane, Polyether and Polyvinylsiloxanether impressions were taken for volumetric dimensional accuracy and stability to measure by Micro-computed tomography (µCT). Impression materials were measured for dimensional stability after the impression was taken, 24 hours later and 144 hours later. For dimensional accuracy 21 impressions and 21 stone models of these impressions were measured. One-way analysis of variance was be used to test for statistically significant difference within groups and Tukey's test was be used to test for across groups with a significance value of $p < 0.05$.

Results: After polymerization, although polyether impression negative was shown to have the highest volumetric expansion, the highest shrinkage was observed in the same group after pouring to dental stone. Stone model of the polyether was observed as the most accurate value of volume in comparison to the master model. The lowest volumetric dimensional change was observed in polyvinylsiloxanether at day 1 (-0.004±0.001%) and the highest change was observed in polyether at day 7 (-0.052±0.004%).

Conclusion: From the standpoint of volumetric accuracy and stability, all three elastomeric impressions are acceptable and µCT is a useful tool for assesments of volumetric dimensional changes.

Keywords: Volumetric dimensional accuracy and stability, Micro CT, polyvinylsiloxanether

1.INTRODUCTION

Elastomeric dental impression materials have been used for several years in the field of dentistry to reproduce oral environment details and to fabricate an accurate fixed and removable prosthesis (1, 2).

An accurate impression is the first and a crucial step in the process of fabricating indirect dental restoration (3). The dimensional stability and accuracy of polyvinyl siloxane and polyether are well documented in the existing literature (1, 4-7). Studies show that these elastomeric impression materials have high precision due to their improved properties (8-10).

Currently, a novel impression material, named as a vinyl siloxanether by the manufacturer, has been introduced to the market. The manufacturer argues that this material has excellent mechanical and flow characteristics, along with good wetting properties in the unset and set condition (11). One of the novelties introduced by this paper is to establish the accuracy of the new formulated vinyl siloxanether impression material, which, to our knowledge, has not yet been explored by the existing literature (12).

Polyether and impression materials are dimensionally accurate for 7 to 14 days (10-15). There are several studies about dimensional changes of impression materials; however, it is difficult to compare and analyze these studies due to differences in experimental methods (16-23). Assessments of dimensional accuracy and stability are essentially made by tophometric and photogrammetric measurements (24-26). Microscopes, laser scanners, coordinate measuring systems and X-ray micro-computed tomography (µCT) are the common devices for dimensional accuracy and stability measurements (17, 27-32).

Among these devices, µCT is superior due to its non-invasive 3 dimensional volumetric measuring feature. Micro computed tomography (µCT) scans three-dimensionally (3D) image dental models and volumetrically compare impressions. 3D structures of materials can be created with high quality resolution. The working principle of the µCT device is based on X-rays passing through the material and collected by a detector and repeated slice by slice along the length of the material. This two-dimensional (2D) data are processed and 3D reconstruction of the images is created (33-36).

Significant developments in both hardware and software decreased slice thickness from conventional CT changes to micrometers and nanometers (37). µCT has been widely used in almost all kind of biomedical research. There are

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many studies for structure and macro morphology of bone, tooth and materials. On the other hand, a systematic research of µCTs ability to accurately show the volume of polymers, restoratives or tooth structures has not yet been demonstrated (38,39). This study addresses this gap in the literature.

Measurements can be examined from impression surface or stone models (33-35). Measuring impressions may be advantageous, as it allows for a more thorough and scientifically correct examination, by restricting the materials involved and demonstrating the interactions. On the other hand, stone model measurements are more aligned with actual clinical and laboratory practice, despite the fact that they complicate the experimental procedure (33-37). The disadvantage of µCT scanning is the expense of the equipment and the time taken to acquire the image (34).

In this study, a µCT-based method to measure volumetric dimensional accuracy and stability of elastomeric impressions materials is presented. To the best of found knowledge, no reports have been published on the method of direct measurements of elastomeric impression materials and therefore the comparison between the impression volume and its stone model. Linear dimensional changes of impression materials are well documented. But there are few studies about volumetric dimensional changes of impression materials and none of them is a direct method.

The purpose of this study therefore is to assess the volumetric dimensional accuracy and stability of the newly formulated PVSE impression material by using µCT in comparison to PE and PVS impression materials. The primary null hypothesis was that there would be no differences in the dimensional accuracy and stability among 3 impression systems.

2.METHODS

2.1. Study Design

An aluminum (7075, Referans Metal) master model representing a single die was prepared according to µCT scanning requirements (Fig. 1). Standard master model with stainless steel is fabricated having one tapered abutment with a base milled on computer numerically controlled (CNS) milling machine. According to µCT scanning requirements abutment had a volume of 18.42 mm^3 and a circular plate with a 3 mm of height and 15 mm of diameter. A special tray from PMMA (polymethyl metacrylate) was made for the study. In order to achieve precision, impression thickness is important and it is necessary to avoid a thin impression layer. The individual tray has a 4 mm equivalent space around the master model (40).

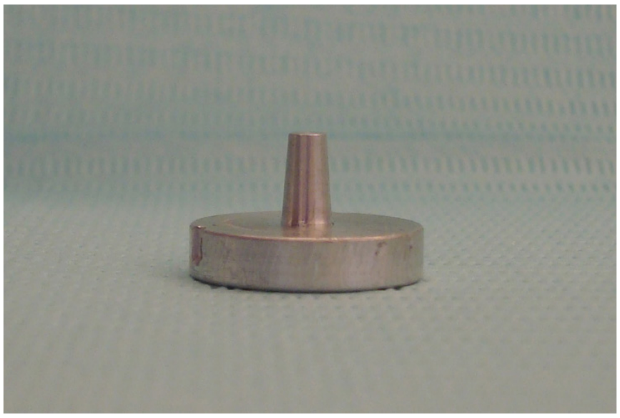

Figure 1. *Aluminum master model*

Impressions were made by perforated PMMA custom tray with a dental surveyor for insertion path. In this study a total of three elastomeric impression materials used: polyether (PE) (Impregum Penta Soft Quick, 3M ESPE; USA), poly vinylsiloxane (PVS) (Virtual Monophase, Ivoclar Vivadent AG, Lichtenstein), vinyl siloxanether, (PVSE) (EXA'lence 370, GC, USA). The impressions were stored under the manufacturer's recommended conditions in a sealed bag.

A total of 60 impressions were made with 10 impressions in each group. The tray adhesive supplied by the manufacturer was evenly applied over the inner surface of the tray. Tray adhesive was applied to the impression surface of the PMMA tray and allowed to dry for 5 minutes before loading the tray. Polyether and polyvinyl siloxanether material was mixed using automix mixing unit (Pentamix 3; 3M ESPE, USA) and the material was loaded into tray for monophase impression technique. Polyvinyl siloxane material was mixed and dispensed through an auto mixing system (Dispenser Gun, Coltène / Whaledent AG, Switzerland) loaded into tray for monophase impression technique. To achieve a homogenous mix, first 2 cm of each of the impression materials were not used. The impression material was then allowed to set as the manufacturer's recommended setting time. After the impression material had set tray was gently removed. Impressions were checked for voids and inaccuracies and were discarded when not found satisfactory.

The impression making steps of various study groups were as follows:

Study Group I: To assess the dimensional accuracy, 30 of the impressions were stored at room temperature for half an hour before pouring with gypsum product (Glaston 3000, Dentsply, USA). To standardize the effect of the setting expansion of the improved stone, the powder was accurately weighed and the water was dispensed using a graduated cylinder in a ratio of 100 gm/20ml in a mixing bowl. The impression was poured and was allowed to set for 60 minutes before being separated. Thirty stone models were measured.

Study Group II: Thirty of the impressions stored for dimensional stability measurements without pouring gypsum. According to the µCT configuration, ten samples from each of the three impression materials were measured for dimensional stability, and measurements were taken in the following order: immediately after the impression was made, 24 hours later and 144 hours later. All the impressions were stored in vacuum bags.

µCT device (Skyscan 1174, Skyscan, Belgium) was used to measure volumetric dimensions of the master model, impressions and dental stones. During acquisition, more than 300 hundred 2-D images were saved through 360° of rotation in digital format. To create a 3-D rendering, the transformed data were stored as projections into new 2D images with a slice thickness of 21.0 µm. The 3-D image was achieved by juxtaposition of 2-D images of adjacent slices.

Figure 2. *Scanning image of impression*

A data collection for reconstruction has shadow image acquisitions from 200 to 400 views with object rotation of more than 360 degrees. For the reconstruction of complete 3-D objects, a serial reconstruction of axial cross-sections can be used. After the serial reconstruction, axial cross-sections of the object can be displayed on the screen. From the reconstruction results, it is possible to reconstruct 3-D objects with the use of an external program (Mimics, Materialise, Belgium). Three hundred seventy one slices were taken for each measurement (Fig. 2).

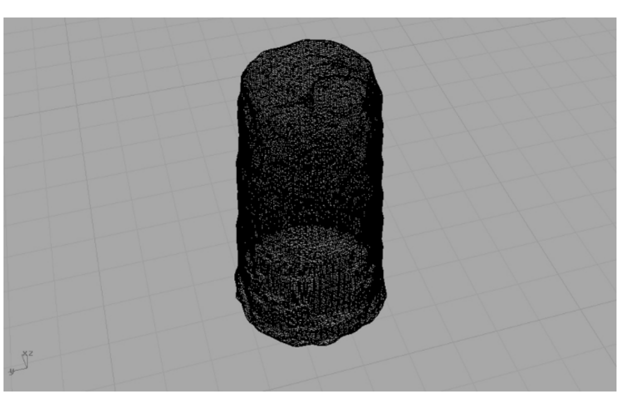

Figure 3. *STL data that obtained from TIFF images*

The raw TIFF (Tagged Image File Format) data that were obtained from measured models were converted to STL (Stereo Lithography) format to reproduce 3D digital models by using Mimics software (Fig 3). Total volumes of the digital models were calculated using 3D Studio Max (Autodesk Inc., USA) (Fig4). The percentage changes in volumes were calculated using the measurement data that was obtained.

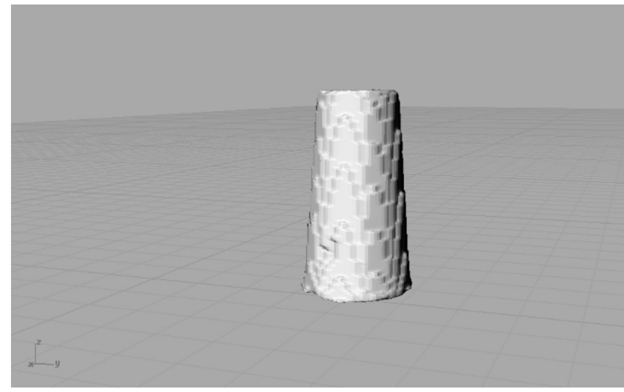

Figure 4. *3D rendered images for calculating volumetric changes*

2.2. Statistical Analysis

One-way analysis of variance (ANOVA) was used to test for statistically significant difference within groups and Univariate ANOVA and Tukey test were used to test across groups with a significance value of $p < 0.05$.

3.RESULTS

3.1.Measurement dimensional accuracy

The measurements obtained from directly scanning the surface of the master model, impression surface and stone model of three impression materials are shown on Table 1. According to µCT scans data, the master model had a total volume of 18.42 mm^3. All impressions were expanded in volume compared to the direct volumetric measurements of the master model. The maximum change was recorded in PE group (19.47 ±0.015 mm^3) and the minimum change was recorded in PVSE group (18.63 ±0.012 mm^3). Stone models obtained from impressions showed adverse reaction. All stone models were shrunk in volume compared to the direct volumetric measurements of the impressions. The maximum change was recorded in PE group (18.37 ±0.016 mm^3) and the minimum change was recorded PVSE group (18.06 ±0.014 mm^3).

Table 1. *Average dimensional volume of the test materials (mm^3)*

Material	Volume (mm^3)
Master model[a]	18.42
PVS impression[b]	19.17 (0.011)
PVS stone model[c]	18.16 (0.013)
PE impression[d]	19.47 (0.015)
PE stone model[e]	18.37 (0.016)
PVSE impression[f]	18.63 (0.012)
PVSE stone model[g]	18.06 (0.014)

Identical lower-case superscript letters denote difference significantly within one experimental formulation (i.e., columns) (ANOVA, Tukey test, p < 0.05).

3.2. Measurement dimensional stability: Percentages of time dependent volumetric change of three impression materials shown in Table 2. All impressions were expanded at 1 and 7 days in volume compared to baseline measurements (0 day). The highest volumetric dimensional change of the impression materials was seen in PE (-0.023 ±0.002) group at day 1 followed by PVS (-0.009 ±0.002) and PVSE (-0.004 ±0.001) respectively. The lowest volumetric dimensional change was observed in PVSE group at day 7 (-0.010 ±0.0003) and the highest change was observed in PE group at day 7 (-0.052 ±0.0004).

Table 2. *Percentage dimensional change of the impression materials by time*

Material	Day	N	Average
PVS[a]	0-1	7	-0.009 (0.002)
PE[b]	0-1	7	-0.023 (0.002)
PVSE[c]	0-1	7	-0.004 (0.001)
PVS[d]	0-7	7	-0.025 (0.003)
PE[e]	0-7	7	-0.052 (0.004)
PVSE[f]	0-7	7	-0.010 (0.003)
	Sum	21	

Identical lower-case superscript letters denote difference significantly within one experimental formulation (i.e., columns) (ANOVA, Tukey test, p < 0.05).

Average percentage change in each type of material has been analyzed statistically using one way ANOVA (Table 3). This method tests the null hypothesis that the changes in PE, PVSE and PVS materials are equal to each other. The validity of the analysis of variances relies on the assumption that the number of samples is distributed with a normal distribution and group variances are equal.

Table 3. *Results of ANOVA for dimensional stability of 3 impression materials*

		Sum of Square	*Df*	Mean Square	F	P
Day 1-	Between grou.	0.0007	2	0.0004	514.236	0.001
	Within groups	0.0000	27	0.0000		
	Sum	0.0007	29			
Day 7	Between grou.	0.0025	2	0.0012	1024.482	0.001
	Within groups	0.0000	27	0.0000		
	Sum	0.0025	29			

After having obtained the results of this analysis, multiple comparisons have been made using the Tukey HSD test (Table 4). The difference between the groups was statistically significant at day 1 and 7 (p<0.05) (Table 4).

The difference between impression and stone model; master model and impression; master model and stone model was statistically significant (p<0.05) (Table 5).

Table 4. *Results of Tukey HSD test for dimensional stability of 3 impression materials (Multiple comparisons)*

Dependent Variable	Mat. (I)	Mat. (J)	Mean diff. (I-J)	p	%95 Confidence int. Lower bound	Upper bound
Day 1 measurements	PVS	PE	-0.0141	0.0000	-0.0152	-0.0130
		PVSE	-0.0086	0.0000	-0.0098	-0.0075
	PE	PVS	0.0141	0.0000	0.0130	0.0152
		PVSE	0.0055	0.0000	0.0044	0.0066
	PVSE	PVS	0.0086	0.0000	0.0075	0.0098
		PE	-0.0055	0.0000	-0.0066	-0.0044
Day 7 measurements	PVS	PE	-0.0258	0.0000	-0.0273	-0.0243
		PVSE	-0.0072	0.0000	-0.0087	-0.0057
	PE	PVS	0.0258	0.0000	0.0243	0.0273
		PVSE	0.0186	0.0000	0.0171	0.0201
	PVSE	PVS	0.0072	0.0000	0.0057	0.0087
		PE	-0.0186	0.0000	-0.0201	-0.0171

Mean differences are significant for alpha=0.05

Table 5. *Results of ANOVA for stone models*

		Sum of squares	Df	Mean sq.	F	P
Impression-Stone model	Between groups	0.0027	2	0.0013	2632.645	0.001
	Within groups	0.0000	27	0.0000		
	Total	0.0027	29			
Master model-impression	Between groups	0.0074	2	0.0037	7874.729	0.001
	Within groups	0.0000	27	0.0000		
	Total	0.0075	29			
Master model-stone model	Between groups	0.0011	2	0.0005	891.492	0.001
	Within groups	0.0000	27	0.0000		
	Total	0.0011	29			

All the three groups of impression materials showed statistically significant differences between impression and stone model; master model and impression; master model and stone model (p<0.05) (Table 6).

Table 6. *Tukey HSD test results of stone models (Multiple comparison)*

Dependent Variable	Mat. (I)	Mat. (J)	Mean diff. (I-J)	P	%95 Confidence int. Lower bound	Upper bound
Impression-Stone model	PVS	PE	-0,0035	0,0000	-0,0044	-0,0025
		PVSE	0,0220	0,0000	0,0210	0,0230
	PE	PVS	0,0035	0,0000	0,0025	0,0044
		PVSE	0,0255	0,0000	0,0245	0,0264
	PVSE	PVS	-0,0220	0,0000	-0,0230	-0,0210
		PE	-0,0255	0,0000	-0,0264	-0,0245
Master model-Impression	PVS	PE	-0,0160	0,0000	-0,0169	-0,0150
		PVSE	0,0295	0,0000	0,0285	0,0304
	PE	PVS	0,0160	0,0000	0,0150	0,0169
		PVSE	0,0454	0,0000	0,0445	0,0464
	PVSE	PVS	-0,0295	0,0000	-0,0304	-0,0285
		PE	-0,0454	0,0000	-0,0464	-0,0445
Master model-Stone model	PVS	PE	0,0115	0,0000	0,0104	0,0125
		PVSE	-0,0057	0,0000	-0,0067	-0,0046
	PE	PVS	-0,0115	0,0000	-0,0125	-0,0104
		PVSE	-0,0171	0,0000	-0,0182	-0,0161
	PVSE	PVS	0,0057	0,0000	0,0046	0,0067
		PE	0,0171	0,0000	0,0161	0,0182

Mean differences are significant for alpha=0.05

4. DISCUSSION

This study evaluates volumetric dimensional accuracy and stability of 3 elastomeric impression materials from the impressions and their final models. Numerous studies have evaluated the dimensional accuracy and the stability of different impression materials (6, 14, 15). The primary null hypothesis of this study was that there would be no differences in the dimensional accuracy and stability among 3 impression systems. Thus, the null hypothesis indicating no difference between the different impression techniques was accepted.

Although the studies are correlated, most of them measured linear dimensional changes (3, 6, 7, 14). Only a few studies measured volumetric dimensional changes. Some investigators preferred to calculate three dimensional results from linear measurements and some preferred to use photometric or topographic methods (23, 24, 26, 27, 30).

In our study µCT device (Skyscan 1174, Skyscan) was used for direct three-dimensional modeling of elastomeric impressions and stone models. Advantages of µCT device are surface and volume measuring, reliability, independent from positioning and operator errors.

Kamegawa et al (33) evaluated using µCT in measuring accuracy of elastomeric impressions. Within the limitations of this study, micro focus X-ray CT indicated that the accuracy is sufficient to measure for direct 3D modeling of elastomeric impressions (34). To be able to make a precise statement, direct measurements of the impressions and their models were made. Therefore the difference between the master model, impression and stone model were evaluated. According to the study results, all the impression materials were expanded in a different volume and this volume differences were compensated by stone models.

From the standpoint of accuracy the three impression materials that we investigated demonstrated a very high dimensional accuracy under the experimental conditions presented, with very small differences between them. Although PE impression was shown to have the highest volumetric expansion after polymerization, the highest shrinkage was observed at the same group after pouring to dental stone. Stone model of the PE group was observed as the most accurate value of volume to the master model.

Our study focused on the dimensional accuracy of the elastomeric impression materials without considering moist, technique, disinfection solution and stone types. Since the dimensional accuracy and stability of impression materials is a primary basis of treatment, all other factors that could affect dimensional accuracy and stability were standardized. There are several studies which explain such factors (6, 16, 25, 28).

Only a few studies are aimed at solely examining the dimensional accuracy of elastomer impression materials. Piwowarczyk et al (20) evaluated short-range dimensional accuracy of 8 elastomeric impression materials (6 polyvinylsiloxane and 2 polyether impressions). Under the conditions of this study, the impression materials tested demonstrated a very high dimensional accuracy similar to our study. Even though dimensional stability was measured linearly, the arithmetic means of the dimensional changes were observed consistent with volumetric dimensional changes in our study.

According to our study results, PE group (19.47 ±0.015 mm^3) expanded more than PVS (19.17 ±0.011 mm^3) and PVSE (18.63 ±0.012 mm^3) after 1 hour of impression procedure. Despite high expansion volume, PE group had the maximum shrinkage after dental stone pouring. PE stone model (18.37 ±0.016 mm^3) showed significantly similar volume to the master model (18.42 mm^3). However all three stone model volume was clinically acceptable.

This study was designed to compare the dimensional accuracy of resultant stone models and dimensional stability of impressions using polyvinyl siloxane, polyether and the vinyl siloxanether elastomeric impression material. The null hypothesis was that no difference would exist in the dimensional accuracy and stability among three different elastomeric impression materials. The hypothesis was rejected since there were significant differences. In most situations, the changes detected were minor amounts and clinical significance.

In this study a statistical analysis of the differences in volumetric dimensions was done between the stainless steel model, impressions and the stone models in order to verify the effects of each impression material. This confirms the hypothesis that selection of impression material is crucial in determining the dimensional accuracy of the impression. This was in accordance to the studies by authors like Chee and Donovan (8) and Craig (13).

For measurement of dimensional accuracy, the study revealed that there was a change in the volumetric dimension of stone cast and impression for all the three groups of elastomeric impression materials. All impressions were expanded in volume compared to the direct volumetric measurements of the master model. The maximum change was recorded in polyether group and the minimum change was recorded in polyvinyl siloxanether group. All stone models shrank in volume compared to the direct volumetric measurements of the impressions. The maximum change was recorded in polyether group and the minimum change was recorded polyvinyl siloxanether group. The similar results were shown by the studies conducted by various authors such as Piwowarczky et al (20) and Craig (13). Polyvinyl siloxanether impression group shows most accurate result among all three groups and the polyether casts were more accurate compared to the casts obtained from polyvinyl siloxanether and polyvinyl siloxane. Similar results were seen in a study carried out by Enkling et al (12).

Many researchers have assessed the dimensional stability of impression materials for periods ranging from 24 hours, a week or 30 days (13, 20, 21). Polyether impression materials were observed as the highest volumetric dimensional change at day 1 and 7. The lowest volumetric dimensional change was observed in polyvinylsiloxane impression materials at day 1 and day 7. In this study, an impression made from polyether should be poured only once and within 24 hours after impression making, because of the distortion of the material over time. Silicone impression material has better dimensional stability than polyether. PVS impressions have shown better dimensional stability then PE. Furthermore PVSE impressions have shown better dimensional stability than PVS and PE. However all three impression materials were measured with high accurate dimensional stability which were in clinically excellent range. In our study similar results were shown as in Thongthammachat et al (22). According to our results PVS, PVSE and PE impressions used in our study is dimensionally acceptable in day 1. PVSE and PVS are highly stabile during the first 1 week period and can be pouring after 1 week. PE impression material has a clinically unacceptable volume loss (%5, 2) at the 1 week and has to be poured at day 1.

5. CONCLUSION

The results of this study may be useful for selecting appropriate impression material. Further studies should be focused on the biological, rheological and wetting properties of this novel impression material to compare with poly vinyl siloxane and polyether and for its clinical acceptability. Also, since the dimensional changes of impression materials are primary basis for all successive treatment steps, all the factors that could exercise a further influence on dimensional accuracy were standardized or excluded in the current study.

µCT device can be successfully used for volumetric dimensional changes of impression materials. However clinical aspect is not so well developed yet, having impression surface and three dimensional measurements is the greatest advantage of the device.

The results of this study showed that newly formulated polyvinyl siloxanether impression material is dimensionally accurate and stabile as well as polyvinyl siloxane and polyether impressions. This impression material should be useful as an alternative to polyether and polyvinyl siloxane in terms of easy handling, accuracy and long term stability.

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