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Tensile Strength of Novel Experimental Hydrophilic Vinyl Polysiloxane Impression Materials Compared to Control and Commercial VPS Impression Materials

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ABSTRACT

Objective: To measure the tensile strength of novel experimental hydrophilic (medium bodied) vinyl polysiloxane impression materials developed from *ab initio* in comparison to control and commercial vinyl polysiloxane impression materials.

Materials and Methods: This experimental study was conducted at the Department of Oral Growth and Development, Bart's and The London School of Medicine and Dentistry, Queen Mary, University of London, UK from 1st Oct 2010 to 28th February 2014. Five novel experimental (medium bodied) VPS impression materials (Exp-I, II, III, IV and V) were developed and evaluated for their effect as crosslinking agent and surfactant on the tensile strength and percent elongation-at-break in comparison to control and three commonly used commercial (medium bodied) VPS impression materials (Aquasil Ultra Monophase, Elite HD Monophase, Extrude. These properties were evaluated using Tenius Olsen (mechanical testing machine).

Results: Aquasil Ultra Monophase (Aq M) had a significantly higher Ultimate Tensile Strength (UTS) compared to all commercial and Experimental VPS. Although Exp-III showed the lowest UTS among all the materials but this was only significant for Aq M. On comparing Exp-I (control) with Exp-II, after adding TFDMSOS into Exp-II there was a slight, but not significant, increase in UTS. After adding the surfactant to hydrophilic Exp-III, IV and V, the UTS decreased slightly, but not significantly, compared to Exp-II. After addition of cross-linking agent (TFDMSOS) there was a significant increase in elongation-at-break of Exp-II compared to the control (Exp-I), which was further significantly increased after incorporating the surfactant (Rhodasurf CET-2) in the Exp hydrophilic VPS formulations (Exp-III, IV and V). Elongation-at-break was significantly increased after incorporating the surfactant (Rhodasurf CET-2) in the Exp hydrophilic VPS formulations (Exp-III, IV and V) compared to Exp-II.

Conclusion: All Exp VPS had significantly higher % elongation-at-break (more than double) than commercial VPS. Percentage elongation-at-break further increased significantly after adding Rhodasurf CET-2 (Surfactant).

Key words: Impression materials, Rhodasurf CET surfactant, Tensile strength, vinyl polysiloxane (VPS)

Author`s Contribution
[1,2]*Conception, synthesis, planning of research and manuscript writing Interpretation and discussion*
[3,4] *Data analysis, interpretation and manuscript writing,*[5,6] *Active participation in data collection.*

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Introduction

Prosthetic rehabilitation of a dental patient is dependent on many elements. Sufficient clinical practices, cautious tooth preparation and luting procedures prove to be the crucial elements in such rehabilitations.[1- 5]. Similarly, the accuracy and detailed reproduction of the impression is also critical for a successful prosthesis and therefore the properties of an impression material from which an impression and then a corresponding cast is made are of utmost importance. An ideal impression material should therefore be able to withstand various forces that are available during different clinical procedures.[3]

Impressions materials come under tensile stresses when they are being removed from the mouth over undercuts. Tensile strength is the maximum amount of stress that a material can bear under tension before failure.[6,7] The elongation (elongation-at-break) is the amount, a material deforms before its failure (Figure 1). Impression materials are more prone to tearing in specific areas such as gingival crevices and interproximal areas and such tearing produces a defected impression, which eventually leads to the construction of an ill-fitting prostheses.[8] Fig 1 shows schematic representation of tensile testing of a typical specimen of impression material.

Elastomeric impression materials are known for their higher elastic properties on removal of impression from the mouth six. Elastomeric impression materials differ from each other in regards to their ultimate tensile strength (UTS) and percent elongation-at-break. Klooster, Logan studied the effects of strain rate on the UTS and elongation-at-break of five elastomeric dental impression materials; two polysulphides (Coe-flex and Omniflex), one condensation silicone (Accoe), one VPS (Reprosil) and one polyether (Impregum), all medium-bodied, with the exception of Omniflex, which was light-bodied.[7] They used three variable crosshead speed rates (100, 200, and 500 mm min^{-1}) for each material. Specimens were stretched axially by applying a tensile load in tension until rupture. The polysulphide impression materials showed the lowest UTS compared to all materials tested. Generally, materials showed higher UTS with the higher strain rates. The polysulphide materials showed the greatest amount of % elongation-at-break followed by polyether then VPS and finally condensation silicone. Generally, materials demonstrated higher values for UTS and percent elongation-at-break occurring at the higher strain rates. For this reason, it is recommended that an impression should be removed from the mouth with a snap, in order to minimize permanent deformation. By rapidly removing the materials from the mouth the polymer chains stretch for a shorter period of time, thus there are less chances of tearing and also better elastic recovery. Hence, impressions should be removed from the mouth and from the cast rapidly. There is very less information about the tensile strength of VPS impression materials and studies available are lacking any quest to improve the tear strength and percent elongation of the material. The objective of this investigation was to comprehensively study five novel experimental VPS impression materials (from 113 pilot studies) for their tensile strength and percent elongation-at-break and to evaluate the effect of crosslinking agent and surfactant on the tensile strength and percent elongation-at-break in comparison to control and three commonly used commercial VPS impression materials.

Materials and Methods

This experimental study was conducted at the Department of Oral Growth and Development, Bart's and The London School of Medicine and Dentistry, Queen Mary, University of London, UK from 1st Oct 2010 to 28th February 2014. Five novel experimental (medium bodied) VPS impression materials (Exp-I, II, III, IV and V) were developed and evaluated for their effect as crosslinking agent and surfactant on the tensile strength and percent elongation-at-break in comparison to control and three commonly used commercial (medium bodied) VPS impression materials (Aquasil Ultra Monophase, Elite HD Monophase, Extrude. These properties were evaluated using Tenius Olsen (mechanical testing machine).

Following were the commercial VPS impression materials used and included in this study, which were randomly selected:

(i) Aquasil Ultra Monophase (Medium-Bodied), (Aq M), purchased from Dentsply, USA.

(ii) Elite HD Monophase (Medium-Bodied), (Elt M), purchased from Zhermack, Italy.

(iii) Extrude (Medium-Bodied), (Extr M), purchased from Kerr, USA.

The ingredients used for preparation of Exp (Exp-I, II, III, IV and V) VPS were:

Vinyl-terminated poly (dimethylsiloxane) (pre-polymer; molecular weight-Mw 62700; Fluorochem, UK), Aerosil R812S (filler - from Lawrence Industries, UK), Rhodasurf CET-2 (Ethoxylatedcetyl-oleyl alcohol; non-ionic surfactant, from Rhodia, UK) and the following were purchased from Sigma Aldrich, UK, poly(methylhydrosiloxane) (Mw 2270; conventional cross-linking agent), tetra-functional (dimethylsilyl) orthosilicate (TFDMSOS; Mw 328.73; novel cross-linking agent), platinum catalyst (0.05 M), palladium (<1 μm; scavenger).

Preparation of experimental VPS impression materials

Five Exp compositions (Exp-I, II, III, IV and V) appeared as the most favorable formulations out of the 113 Formulations.The main differences between these five formulations included the incorporation of a novel cross-linking agent, TFDMSOS, to improve the tear strength and a novel non-ionic surfactant (Rhodasurf CET-2; Ethoxylatedcetyl-oleyl alcohol) to improve wetting properties of the material. Exp-I was used as a control for Exp-II. The catalyst paste was same for both the formulations (Exp-I and II).

Exp-II was used as a control for Exp-III, IV and V. The catalyst paste was same for all the hydrophilic formulations (Exp-III, IV and V).

Measurement of Tensile Strength

Tensile testing was carried out on the Tinius Olsen which was calibrated before use. The specimens (n=12 per material) were held in self-tightening grips and then extended at a constant test speed of 500 mm min^{-1} until rupture, and the force (N) required to break the specimen, and the extension (mm) of the specimen at failure were recorded (12,13) (Figure 2). Stress and strain values were calculated using equations 1 and 2 respectively.

$$\sigma = \frac{F}{A} \qquad \text{Equation 1}$$

Where

σ is the stress (MPa), F represents the force (N), A is the sample cross-sectional area (m^2)

$$\varepsilon = \frac{(L-..L_0)}{L_0} \text{ x } 100 \qquad \text{Equation 2}$$

Where

ε represents the strain (%), L_0 is the original length (mm) at rest, L is length (mm) after applied stress.

Results

Figure 3 shows the results for the mean ultimate tensile strength (UTS) and % elongation-at-break for all commerciand Exp VPS impression materials. All Comml and Exp VPS impression materials demonstrated significant differences ($p<0.05$) in UTS. Aq M had a significantly higher (Tukey's HSD test) UTS (3.31 MPa ± 0.19 MPa) compared to all Comml and Exp VPS. Although Exp-III showed the lowest UTS (2.19 MPa ± 0.21 MPa) among all the materials, this difference was only significant for Aq M. Elt M, Extr M and Exp-I had relatively similar mean values, which were not significant ($p>0.05$). On comparing Exp-I (control) with Exp-II, it was noticed that after adding TFDMSOS into Exp-II there was a slight, but not significant, increase in UTS. It was also observed that after adding the surfactant to hydrophilic Exp-III, IV and V, the UTS decreased slightly, but not significantly, compared to Exp-II (control; Figure 3).

All Exp VPS showed significantly higher elongation-at-break (%) than the Comml VPS. Exp-V exhibited significantly higher values (981.92 % ± 51.08 %) for % elongation-at-break, while significantly lower values were shown by Elt M (114.88 % ± 15.05 %) compared with all materials; these were not significantly different for Aq M. On comparing the Comml VPS with each other, Extr M had significantly higher % elongation-at-break followed by Aq M and then Elt M, and the difference between Aq M and Elt M was not significant. On comparing the Exp VPS with each other, Exp-I demonstrated significantly lower elongation-at-break. It is worth noting that on addition of cross-linking agent (TFDMSOS) there was a significant increase in elongation-at-break of Exp-II compared to the control (Exp-I), which was further significantly increased after incorporating the surfactant (Rhodasurf CET-2) in the Exp hydrophilic VPS formulations (Exp-III, IV and V; Figure 3). Generally, materials with high UTS had lower percent elongation-at-break. However, this trend was not strictly applicable for all Comml and Exp VPS, such as Aq M, which had the highest UTS but it's percent elongation-at-break was not the lowest (second lowest). Similarly, Exp-II had the second highest UTS, but its elongation-at-break was higher than all Comml and Exp-I materials (Figure 3).

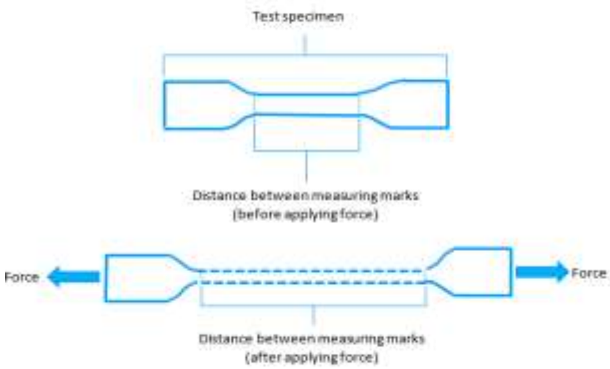

Figure 1: Schematic representation of tensile testing of a typical specimen of impression material

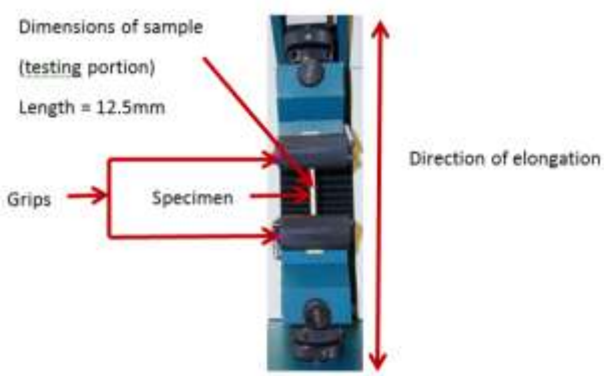

Figure 2: A typical tensile test specimen set up (n=12)

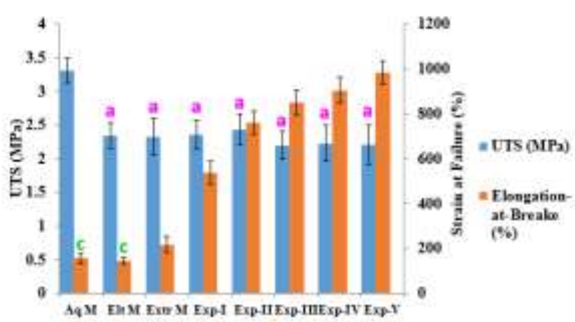

Figure 3: Mean (± standard errors; n=12) UTS and % elongation-at-break of Comml and Exp VPS immediately after setting. Similar letters indicate no significant difference (p>0.05)

Discussion

The UTS of impression materials is an important parameter, which indicates the maximum stress that a material can withstand while being stretched before breaking. Strain at failure is the percentage elongation-at-break of the material. The UTS of an impression is dependent on many factors such as the choice of material, relief properties from the tooth and the perfect timing or rate of impression removal.[14] From clinical point of view, materials with higher tensile strength are considered superior than the ones with lower tensile strength and therefore an ideal impression can be taken only once the impression material is able to demonstrate maximum energy absorption without tearing and with minimal distortion. For the above reasons the tensile strength and percent elongation-at-break were evaluated in the current work and a possibility to improve them was taken as a challenge.[14] UTS for all Comml and Exp VPS investigated were in the range of 2.21 to 3.31 MPa. On comparing these results with a previous study by Klooster, Logan, who investigated the UTS and elongation-at-break of VPS, condensation silicone, polyether and polysulphide impression materials, it was seen that all the Comml and Exp VPS in this study had higher UTS. The values for Klooster et al's materials were in the range of 0.96 to 2.07 MPa.[7] In the case of elongation-at-break, all Exp VPS had significantly higher percent elongation-at-break (more than double) than Comml VPS. Furthermore, Exp-II showed a higher % elongation-at-break (761.99%) compared to the control (Exp-I; 538.44%). The former contains the novel cross-linking agent (TFDMSOS), and it is assumed that this component is responsible for the increase in % elongation-at-break, due to being tetra-functional, as discussed in detail earlier in the materials and method section. [7,14]

On comparing this data with Lawson, Burgess results, who investigated the elongation-at-break percent of six elastomeric impression materials; five VPS and one hybrid, the Exp VPS had much higher values (more than double) for percent elongation-at-break compared to their materials. Also, all Exp VPS of the current study showed much higher values for percent elongation-at-break (more than double) than those reported by Klooster *et a*l, for some elastomeric impression materials.[7,15] A high percent elongation-at-break is a very clinically relevant property, provided the material has the required elastic recovery. According to McCabe and Walls, polysulphide impression materials can withstand 700% elongation before failure. Interestingly all the Exp VPS investigated in this study, with the exception of Exp-I, exhibited higher percent elongations (761.99% to 981.92%). In the case of the polysulphides some of the strain is non-recoverable, which is the major drawback of these materials, while in the case of the Exp VPS, the elastic recovery was comparable to all Comml VPS. All Exp VPS, with the exception of Exp-I, additionally contained TFDMSOS as a cross-linking agent. Therefore, it is inferred that this component increased cross-linking within the materials, thus contributing to the increase in their percent elongation-at-break.[16]

Conclusion

All Exp VPS had significantly higher percent elongation-at-break (more than double) than commercial VPS. Percentage elongation-at-break further increased significantly after adding Rhodasurf CET-2 (Surfactant).

Recommendations

The specific properties of an impression material dictate the choice of an impression material for a particular application. With regard to the UTS and percent elongation at break tested,

All Exp VPS had significantly higher percent elongation-at-break (more than double) than commercial VPS, and Exp-II showed a higher percent elongation-at-break compared to the control (Exp-I). The former contained the novel cross-linking agent (TFDMSOS), and it is assumed that this component is responsible for the increase in percent elongation-at-break due its' tetra-functional structure.

Elongation-at-break was significantly increased after incorporating the surfactant (Rhodasurf CET-2) in the Exp hydrophilic VPS formulations (Exp-III, IV and V) compared to Exp-II.

This study can be a great help to design a new VPS impression material with much better mechanical properties.

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