Effect of Water Absorption on the Rheological Properties of Acrylic Tissue Conditioners

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Abstract:
Purpose: This investigation examined the influence of water absorption on creep compliance and fluidity of acrylic tissue conditioners.
Methods: Six commercially available acrylic tissue conditioners were used in this investigation. All materials were mixed for 20 sec according to the mixing proportion recommended by the manufacturer and allowed to set at room temperature (23±0.5 °C). Each specimen was stored immediately after preparation in an air cabinet or in a water bath maintained at either 23±0.5 °C or 37±0.5 °C. Two measurements were taken using an electronic balance to determine water absorption and using a creep testing instrument under constant load to examine creep behavior.
Results: The specimen weight in all materials containing ethyl alcohol decreased markedly from the start of immersion in water. In the case of ethyl alcohol-free material, the specimen weight increased immediately after immersion in water. The relative creep compliances (J(2)95/23, J(60)95/23, and J(120)95/23) and the relative fluidity (φ95/23) decreased linearly with increases in the amount of water absorption.
Conclusion: With an increase in the amount of water absorption, each material showed increased resistance to deformation and accelerated the deterioration of its flow property.

Key words: tissue conditioner, water absorption, creep measurement, creep compliance, fluidity

Introduction
With the increasing elderly population of, the number of patients requesting advanced treatment technology has increased gradually. Tissue conditioner plays an extremely important role in complicated restorative treatment and, therefore, the frequency of tissue conditioner usage has also increased in recent years.4–14 Tissue conditioner is principally used to recover oral mucosa injured by either acute or chronic trauma,5–8 by reducing the overload produced in the oral cavity.9–11 The important properties required of an excellent material is the ability to maintain appropriate elasticity and superior fluidity observed at a relatively early stage after setting.12–14 The rheological property of materials with low viscosity, such as tissue conditioner, is markedly affected by the amount of water absorbed.

The goal of this investigation was to examine the relationship between both the creep compliance and fluidity with the amount of absorbed water, and to discuss the effect of absorbed water on the rheological properties of tissue conditioners.

Materials and Methods
The six commercially available tissue conditioners used in this investigation are listed in Table 1, together with the code, manufacturer, Lot No. and mixing proportion of powder to liquid. All materials were mixed for 20 sec using a glass cup designed for tissue conditioners, according to the mixing proportion recommended by the manufacturer, transferred to a cylindrical stainless steel mold (φ16 mm x 2 mm) and allowed to set at room temperature (23±0.5 °C). Each specimen was removed from the mold 60 min after mixing and stored immediately in an air cabinet or in a water bath maintained at either 23±0.5 °C or 37±0.5 °C. After storing in air (23±0.5 and 37±0.5 °C) and in water (23±0.5 and 37±0.5 °C) for 23 and 95 hours, respectively, each creep measurement was performed. In addition, every three specimens for these condition (times, temperatures and environmental conditions of specimen, respectively) were prepared.
1. Measurement of water absorption
The measurement of water absorption was carried out using an electronic balance (FH-400, A&D, Tokyo, Japan) and a water bath (HOB-500, As ONE, Tokyo, Japan) and was continued for specimens soaked in distilled water for 167 hours at a temperature of 37±0.5°C. The determination of water absorption was performed at 0, 2, 5, 9, 23, 47, 95 and 167 hours from the start of immersion. Three specimens for each material were prepared and their mean values (weight / surface = mg / cm²) were calculated.

2. Creep measurement
The apparatus used for the creep measurement is an experimental compressive test instrument. A schematic representation of the instrument is shown in Fig. 1. This instrument consists of a metal stage (for the specimen), a rod for applying a load to the specimen, a weight, an electric transducer (AC-5L, Shinko Denshi, Tokyo, Japan) for detecting a fine movement of the rod produced by the load, the output of which is fed to an amplifier (M-5, Shinko Denshi, Tokyo, Japan), and a pen recorder (ID43005B122, Matsushita, Tokyo, Japan). There was an adequate correlation (r = 0.9999) between the output of the instrument and the actual dimension. The creep measurement was carried out for 120 sec under a load (1.96 N) approaching the proportional limit at either 23±0.5°C or 37±0.5°C, and was performed for the respective specimens stored for 23 hours and 95 hours in air or distilled water. The final surface of the specimen was 2 cm². Three specimens for each material were prepared and their mean values were calculated.

3. Determination of creep compliance (J(t)) and fluidity(φ)
The creep compliance J(t) and fluidity(φ) were calculated using equations (1) and (3) as follows:
\[ J(t) = \gamma(t) / f \]  
Where \( \gamma(t) \) is the strain and f is the stress. The magnitude of J(t) derived from the theory of viscoelasticity is expressed by the following equation:\[ J(t) = J_g + (J_e - J_g) \psi(t) + t/\eta \]  
Where \( J_g \) is the compliance at \( t = 0 \), \( (J_e - J_g) \psi(t) \) is the compliance derived from delayed deformation and \( \eta \) is the coefficient of viscosity. In addition, the fluidity(φ) is expressed by the following equation:\[ \phi = 1 / \eta = (J_b - J_a) / (t_b - t_a) \]

In addition, the values of J(t) or φ were also represented as the relative value (the ratio of the specimens maintained respectively for 23 hours and 95 hours). The test specimens used were respectively three for six materials.

4. Statistical analysis
With regard to the results of this investigation, Pearson's correlation coefficient was used in order to determine the relation between both the relative creep compliances (\( J(23)_{95/23} \), \( J(60)_{95/23} \) and \( J(120)_{95/23} \)) and the relative fluidity (\( \varphi_{95/23} \)) with water absorption, using the program “Stat

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Table 1  Materials used in this study.

<table>
<thead>
<tr>
<th>Code</th>
<th>Material</th>
<th>Manufacture</th>
<th>Lot No.</th>
<th>Mixing proportion</th>
</tr>
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<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Powder(g)</td>
</tr>
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<td>A</td>
<td>Coe-comfort™</td>
<td>GC</td>
<td>306261</td>
<td>6</td>
</tr>
<tr>
<td>B</td>
<td>Fictioner</td>
<td>Nissin</td>
<td>DG</td>
<td>2</td>
</tr>
<tr>
<td>C</td>
<td>Fitsofter</td>
<td>Dentsply-Sankin</td>
<td>381-274</td>
<td>3.1</td>
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<tr>
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<td>Hydro-cast</td>
<td>Sultan Chemists</td>
<td>520311505</td>
<td>1</td>
</tr>
<tr>
<td>E</td>
<td>Tissue conditioner</td>
<td>GC</td>
<td>311066</td>
<td>2.4</td>
</tr>
<tr>
<td>F</td>
<td>Tissue conditioner</td>
<td>Shofu</td>
<td>P:10242 L:100228</td>
<td>6</td>
</tr>
</tbody>
</table>

Fig. 1  Schematic representation of apparatus used.
Effect of Water Absorption on the Rheological Properties of Tissue Conditioners

Fig. 2  Variation of water absorption with immersion time of 6 tissue conditioners. Water absorption was measured for 167 hours from the start of immersion in distilled water at 37°C. The respective values represent the mean and the error bars denote the standard deviation.

View "J 5.0" (Hulinks, Tokyo, Japan). The level of significance was set at P < 0.05.

Results

1. Water absorption

The weight of the specimen in all materials, except B, decreased markedly from the start of immersion in water (37°C), as shown in Fig. 2, and reduced continuously for 23 hours. The magnitude of this decrease was the largest in D material and reduced in the order of E, F, C and A. In the case of B, the increase in specimen weight began immediately after immersion in water and continued for 167 hours.

2. Creep compliance (J(t)) and fluidity (φ)

The variation in creep compliance (J(t)) with time of each material maintained for 23 or 95 hours in an air cabinet or a water bath at either 23±0.5°C or 37±0.5°C is shown in Fig. 3 and Fig. 4, respectively. As the material was stored at a high temperature, the mean value of J(120) increased greatly. The values (J(120)s) of materials immersed in water (for 95 hours and at 37°C), except A, became larger compared with those of materials maintained in air. With regard to the creep compliances (J(2), J(60) and J(120)) of the specimens maintained respectively for 23 hours and 95 hours in water (37°C), the ratios of J(2)_{95} to J(2)_{23}, J(60)_{95} to J(60)_{23} and J(120)_{95} to J(120)_{23} (relative compliance: J(2)_{95/23}, J(60)_{95/23} and J(120)_{95/23}) decreased with increases in absorbed water, as shown in Fig. 5. The coefficient of correlation (r) between the relative creep compliance and the water absorption was -0.71 for J(2)_{95/23} (P > 0.05), -0.77 for J(60)_{95/23} (P < 0.05) and -0.77 for J(120)_{95/23} (P < 0.05).

The ratio of fluidity φ_{95} to φ_{23} (relative fluidity: φ_{95/23}) decreased with increases in absorbed water, as shown in Fig. 6. The coefficient of correlation between φ_{95/23} and water absorption was -0.80 (P < 0.05).

These results showed that the relative compliance or relative fluidity decreased statistically with an increase in absorbed water.

Discussion

All materials, except B, showed a marked decrease in specimen weight immediately after the start of immersion in water and reached their respective minimum values 23 hours after immersion. Differences among the minimum values of each material were observed. It is considered that this difference was caused by the amount of alcohol included as a component of the material. In the case of B material, which does not include alcohol, there was no apparent decrease in the specimen weight during the initial stage of immersion in water. In addition, regardless of whether the specimen was maintained in air or in water, the value of J(120) definitely increased with an increase of environment temperature of the specimen. This finding suggests that the specific volume of a material increases with a rise in the environment temperature, the amount of water absorbed by the specimen increases and the material is apt to flow due to the increased space between the molecules. In the case of materials maintained in air (23°C) for 23 hours, each mean value of creep compliance (J(120)) was smaller than those of the materials maintained at 37°C. J(120) of D material did not change with a temperature increase. On the other hand, the J(120) of the materials stored in water at 37°C became higher than those of the materials stored in water at 23°C. This tendency was also observed in the case of materials stored in air or in water for 95 hours.

In addition, on comparison between the materials respectively stored in water (23 and 37°C) for 23 hours or 95 hours, B material showed peculiar behavior and the values of J(t) with time were
Fig. 3  Variation of creep compliance (\(J(t)\)) with time of 6 tissue conditioners. (1): maintained 23 hours in air at 23 °C, (2): maintained 23 hours in water at 23 °C, (3): maintained 23 hours in air at 37 °C, (4): maintained 23 hours in water at 37 °C. The respective values represent the mean and the error bars denote the standard deviation.

Fig. 4  Variation of creep compliance (\(J(t)\)) with time of 6 tissue conditioners. (1): maintained 95 hours in air at 23 °C, (2): maintained 95 hours in water at 23 °C, (3): maintained 95 hours in air at 37 °C, (4): maintained 95 hours in water at 37 °C. The respective values represent the mean and the error bars denote the standard deviation.
the largest compared with other materials. This phenomenon is probably produced by differences in the diffusion rate of the liquid component into the powder due to differences in the particle size,19 distribution and the molecular weight of the powder component,20 as demonstrated by Parker and Braden.

In the case of J(2)95/23 (compliance depending upon principally instantaneous strain in creep), J(60)95/23 (compliance depending upon retarding effect) and J(120)95/23 (compliance including large flow element), an adequate correlation was obtained between the relative creep compliance (J(2)95/23, J(60)95/23 and J(120)95/23) and the water absorption. This indicates that each compliance decreases with increases in the amount of water absorbed as well as increases in distortion resistance.

An adequate correlation was obtained between the degree of fluidity determined using equation (3) derived from the theory of viscoelasticity and the amount of absorbed water. With increases in the amount of absorbed water, the ratio of fluidity (φ95/23) decreased. It is required that excellent tissue conditioners possess appropriate elastic properties and superior flow properties observed at a relatively early stage after setting. In the present investigation, however, the distortion of the material decreased and the resistance of fluidity increased. This fact indicates that the properties of commercially available tissue conditioners are widely different from the desirable behavior. Therefore, it is considered that these findings become an important factor for determining a clinically favorable property of tissue conditioner.

In this investigation, however, it was impossible to estimate a clinically acceptable deterioration of flow property or an elastic recovery of materials. It will be necessary to continue additional investigation on this subject.

**Conclusion**

The effect of absorbed water on the rheological properties of six acrylic tissue conditioners was investigated. In the case of materials containing alcohol, the specimen weight decreased immediately after the start of immersion in water. This phenomenon is caused by the elution of alcohol. However, the value of creep compliance decreased with increases in the amount of absorbed water and the fluidity decreased as well. This phenomenon is produced by differences in the plasticizing efficiency between alcohol and water.

**References**
