INTRODUCTION

The last few years have witnessed an increased demand for a restorative material that provides good aesthetic and mechanical properties. This resulted in an increase in the use of resin-composites in both anterior and posterior restorations. Amalgam restorations have declined in popularity due to aesthetic considerations, possible mercury poisoning, and other factors.

Handling properties of composite filling material play a major role in the selection of the material for a proposed filling and in its clinical success. A dentist will not prefer to use a material that cannot be easily handled, or does not produce an acceptable filling. An ideal material would remain static until a force was applied. Regarding handling properties, resin-composite have a major drawback; lack of ‘feel’ or ‘packability’, which is a major characteristic of amalgam. This characteristic facilitates adequate adaptation of the restorative material to the cavity floor, walls and as well as to optimizing proximal contact areas.

Currently used procedures for resin-composite placement in a prepared cavity may sometimes cause voids and gaps in restorations. In a clinical setting, presence of voids and gaps may lead to discoloration, decreased wear resistance and eventually replacement of a restoration. In a study by Kreulen et al., clinical performance of posterior resin-composites was evaluated using radiographic evaluation. It was found that 52.9% of restorations had voids. Significant differences were found between various brands of composites.

Consistency or packability of any resin-composite plays a major role in reducing voids and bubbles in a restoration. An ideal material should flow into every part of prepared cavity while maintaining some consistency, to be easily applied in a class V cavity and maintain their shape before curing.

Similar to clinical settings, the dentist has to apply force multiple times for proper contouring of a restoration. There is a need to understand how a restorative material behaves under a multiple compressive force in terms of consistency or packability, as composite restorative materials are sticky so there is a chance of dislodging of the material during this situation.

Aim of this study was to investigate effect of variation in morphology and size of filler particles, temperature and increase in condensation speed on packability of resin-composites. The null hypotheses tested were; packability under a continuous cyclic force did not vary with a change in resin-composite filler morphology, change in temperature and the rate of cyclic packing force did not affect packability of the resin-composite.

MATERIALS AND METHODS

Eight experimental light-cured resin-composites (RZDn series) were tested. Each material was placed in a cylindrical mould at 26 or 32ºC. A flat-ended stainless-steel probe (φ=6 mm) was mechanically lowered with two different speeds 2 and 8 mm/s onto and into at the surface of the unset sample until a compressive force of 1 N was reached. This was repeated for five cycles, and from each cycle Fp was calculated. All spherical and irregular filler particle resin-composites showed a decrease in Fp with increase in number of compressions. Increase in temperature also decreased Fp, but this effect was not very prominent in the case of irregular filler resin-composites. Filler particle morphology, increase in temperature and compression cycle speed has a prominent effect on packability of resin-composites.

Effect of variation in morphology and size of filler particles, temperature and increase in condensation speed on packability of resin-composites was investigated. Eight experimental light-cured resin-composites (RZDn series) were tested. Each material was placed in a cylindrical mould at 26 or 32ºC. A flat-ended stainless-steel probe (φ=6 mm) was mechanically lowered with two different speeds 2 and 8 mm/s onto and into at the surface of the unset sample until a compressive force of 1 N was reached. This was repeated for five cycles, and from each cycle Fp was calculated. All spherical and irregular filler particle resin-composites showed a decrease in Fp with increase in number of compressions. Increase in temperature also decreased Fp, but this effect was not very prominent in the case of irregular filler resin-composites. Filler particle morphology, increase in temperature and compression cycle speed has a prominent effect on packability of resin-composites.

Keywords: Resin composite, Cyclic loading, Filler morphology, Packability

Color figures can be viewed in the online issue, which is available at J-STAGE.
Received Jun 10, 2016; Accepted Nov 4, 2016
doi:10.4012/dmj.2016-215   JOI JST.JSTAGE/dmj/2016-215
Table 1: Resin composite restorative materials used for the investigation

| Resin-composite | Filler particles |
|-----------------|-----------------|
|                 | Shape           | Size (nm) | wt%  |
| RZD 102         | Spherical       | 100       | 72.3 |
| RZD 107         |                 | 250       | 72.6 |
| RZD 106         |                 | 500       | 72.6 |
| RZD 114         |                 | 100, 250, 1,000 (1:1:2) | 72.0 |
| RZD 105         |                 | 1,000     | 72.5 |
| RZD 111         | Irregular       | 450, 1,000 (1:3) | 76.4 |
| RZD 109         |                 | 1,000     | 76.4 |
| RZD 110         |                 | 1,500     | 76.4 |

The resin matrix consisted of Bis-GMA, UDMA, TEGDMA and the filler volume fraction was constant at 56.7%, for all materials. Spherical (SiO₂); Irregular (Ba-Al-B-silicate glass)

The cavity packing force for repeated condensation was calculated using a sensitive stress strain instrument—Fig. 1 (TA.XT2i, Stable Micro Systems, Godalming, Surrey, UK). The analyzer was comprised of a flat end stainless-steel cylindrical probe (φ=6 mm) connected to a force transducer to measure the force acting on the probe. Modifications to the analyzer were carried out as follows: a thermostatically controlled frame (φ=70 mm) was constructed and fixed to the stainless steel stand, this frame contained a cylindrical mould cavity (φ=7, depth=5 mm) (Fig. 2), into which the composite sample to be tested, was placed. Temperature of the mould cavity was regulated using an embedded thermostat and adjustable power supply unit, with a thermocouple in close proximity to the sample.

For each run first experimental materials were placed in side the cylindrical mould cavity (φ=7, depth=5 mm) without applying any extra pressure or tapping of the material and temperature was set at either 26 or 32°C representing the room and oral cavity temperature respectively. Then probe was mechanically lowered with a pre-test speed of 5 mm/s to a trigger distance of 2 mm from the surface of unset sample. After reaching to the trigger distance data acquisition commenced and probe move further with a test speed of 2 or 8 mm/s up to and into the material to a target depth of 2 mm and then the probe moved back to the trigger distance of 2 mm above the surface with the same speed of 2 or 8 mm/s.
This sequence was repeated 5 times. The different test conditions used in these experiments are summarized in Table 2.

In order to analyze the data, linear regression was used to study the linear relationship between a dependent variable compressive force and two independent variables speed and temperature.

**RESULTS**

Compressive force (N) and tensile force (N) data were plotted against time (s) for the downward and upward movement respectively. A specific force/time profile was observed (Fig. 3), depending mainly on material composition and temperature.

For evaluation of cavity packing force, only the compressive part of the data was considered and maximum packing force ($F_p$, N) was calculated from each cycle (Fig. 3). These forces were not same during five cycles, but decreased in a non-linear manner in most of the cases (Table 3). The mean values and standard deviations of $F_p$ for spherical, irregular and multimodal resin-composites are graphically presented in Figs. 4, 5 and 6 respectively. Whereas the influence of change in the temperature and compression speed on the packability of the experimental materials have been determined by linear regression as shown in Table 3 and $r^2$ values shows that the change in temperature and compression speed in the most of the cases had a direct influence on packability of experimental composite materials.

In case of spherical filler resin-composites with repeated compression (Fig. 4), all materials showed a downward trend for mean $F_p$, with an increase in number of cycles and increase in temperature from 26 to 32°C. Along with that, increase in the compression cycle speed from 2 to 8 mm/s also resulted in an increase in packing of the materials.

For irregular filler resin-composites, the general trend was that repeated compressive forces resulted in a decrease in $F_p$ and an increase in the temperature from 26 to 32°C had less effect on packability of the materials, whereas an increase in the speed of compressive force cycle resulted in a decrease of the $F_p$ in the most of the cases (Fig. 5).

In multimodal resin-composites, mean $F_p$ was less than 1 N and the increase in compressive cycle speed and temperature of the material had very low effect on the packability of the materials (Fig. 6).
Table 3  Influence of change in temperature and compression speed on the packability of the composite, determined by linear regression

| No. | Experimental materials (RZD series) | Temperature (°C) | Speed (mm/s) | $r^2$ | Slope |
|-----|------------------------------------|-----------------|--------------|-------|-------|
| 1   | 102 100 nm Spherical               | 26              | 2            | 0.22  | −0.066|
|     |                                    | 8               | 0.49         | −0.107|
|     |                                    | 32              | 0.53         | −0.062|
|     |                                    | 8               | 0.49         | −0.137|
| 2   | 107 250 nm Spherical               | 26              | 2            | 0.44  | −0.068|
|     |                                    | 8               | 0.89         | −0.0026|
|     |                                    | 32              | 0.63         | −0.035|
|     |                                    | 8               | 0.48         | 0.075 |
| 3   | 106 500 nm Spherical               | 26              | 2            | 0.88  | 0.045 |
|     |                                    | 8               | 0.53         | −0.071|
|     |                                    | 32              | 0.94         | 10    |
|     |                                    | 8               | 0.56         | −0.066|
| 4   | 105 1,000 nm Spherical             | 26              | 2            | 0.61  | −79   |
|     |                                    | 8               | 0.50         | −0.036|
|     |                                    | 32              | 0.62         | −0.061|
|     |                                    | 8               | 0.75         | −0.064|
| 5   | 108 700 nm Irregular               | 26              | 2            | 0.27  | 0.0075|
|     |                                    | 8               | 0.36         | −0.001|
|     |                                    | 32              | 0.71         | −0.075|
|     |                                    | 8               | 0.65         | −0.036|
| 6   | 109 1,000 nm Irregular             | 26              | 2            | 0.71  | −0.6357|
|     |                                    | 8               | 0.42         | −0.03 |
|     |                                    | 32              | 0.69         | −0.042|
|     |                                    | 8               | 0.33         | −0.014|
| 7   | 110 1,500 nm Irregular             | 26              | 2            | 0.20  | 0.011 |
|     |                                    | 8               | 0.45         | −0.026|
|     |                                    | 32              | 0.53         | −0.036|
|     |                                    | 8               | 0.53         | −0.029|
| 8   | 114 100, 250, 1,000 (1:1:2)        | 26              | 2            | 0.50  | 0.0164|
|     | Multiple spherical                | 8               | 0.50         | −0.01 |
|     |                                    | 32              | 0.53         | 29    |
| 9   | 111 450, 1,000 (1:3)               | 26              | 2            | 0.52  | −0.089|
|     | Multiple irregular                | 8               | 0.55         | −0.0156|
|     |                                    | 32              | 0.616        | −0.079|
Fig. 4  Cavity packing force for spherical filler partials with repeat compression (n=5).

a: RZD 102 at 26°C, b: RZD 102 at 32°C, c: RZD 107 at 26°C, d: RZD 107 at 32°C, e: RZD106 at 26°C,
f: RZD106 at 32°C, g: RZD 105 at 26°C, h: RZD 105 at 32°C.
Fig. 5 Cavity packing force for irregular filler partials with repeat compression (n=5).  
a: RZD 109 at 26°C, b: RZD 109 at 32°C, c: RZD 110 at 26°C, d: RZD 110 at 32°C.

Fig. 6 Cavity packing force for multimodal filler partials with repeat compression (n=5).  
a: RZD 114 at 26°C, b: RZD 114 at 32°C, c: RZD 111 at 26°C, d: RZD 111 at 32°C.
DISCUSSION

Bis-GMA has been the main monomer used in all resin-composites, because it exhibits a relatively low polymerization shrinkage (around 6%), rapid hardening by free-radical polymerization, low volatility and good mechanical properties when cured\(^9\). Nevertheless, it is of a very high viscosity. A low viscosity monomer (mostly TEGDMA) is added to improve its workability and to increase the amount of the inorganic filler in the resin matrix\(^9\), but this led to an increase in polymerization shrinkage\(^11\). The addition of inorganic fillers changes the rheological behavior of uncured resin-composite and result in an increase in viscosity and consistency of the material\(^4,10\).

Resin-composites are now the material of choice for not only anterior aesthetic restorations but also for the posterior restorations. It is imperative to evaluate their rheological properties. Regarding handling properties, ideal restorative materials should have a balance between flow and viscosity, resistance to slump and also should be easy carved for the occlusal anatomy and most importantly to be easily packable especially in the posterior region to provide proper adaptation to walls of the prepared cavity\(^2,12-14\).

The technique used in this investigation is very useful and reproducible for characterizing the effect of multiple compressive forces on the packability of experimental resin-composites.

Lee et al.\(^10\) reported that there was no direct linear relationship, but a weak relationship between filler volume percentage and viscosity of the composites, and there were many multifactorial factors determining the resin-composite consistency. All experimental resin-composites tested in this study had the same overall inorganic filler volume (56.7%) and same resin matrix composition (Bis-GMA, UDMA and TEGDMA (Table 1)). The filler size (100 to 1,500 nm), shape and weight (%) varied among the eight different materials and was in the same order as that of the commercially available 'equivalent' (Tetric Ceram) which has 60 %vol. filler fraction (79 wt%). Thus the factors affecting the packability of the model resin composites will be the filler size and/or shape. For the multimodal materials, it was not appropriate to represent a mean value for filler size, thus they were investigated as a separate group\(^13,16\).

In the case of the spherical model resin-composites, repeated compression resulted in a decrease in the \(F_p\) (Fig. 4). This might be due to that with multiple compressions, after each compression there was more settling of the particles within the resin matrix resulting in less resistance to the target force of 1 N. This trend was more prominent with the increase in temperature, as with an increase in temperature, a decrease in the viscosity of the resin matrix was noticed, resulting in comparatively less \(F_p\). This was in agreement with a number of studies that showed a decrease in viscosity with an increase in temperature\(^16,17\). Along with that, an increase in filler size also resulted in a decrease in \(F_p\) which might be explained by the fact that as the filler size was smaller, the number of filler particles was higher for identical filler volumes, and thus the increased surface area resulted in a greatly increased interaction between the resin matrix and filler particles, and between filler particles resulting in an increase in resistance to the packing force\(^10\).

Increase in the speed of the oscillating force from 2 to 8 mm/s resulted in a decrease in \(F_p\). It might be due to increase in speed of the oscillating force there is less time for the sample material to recover its elastic deformation during the recovery phase, resulting in less resistance to the packing force during the next compression. This behavior was similar to the shear thinning as observed in number of studies done to characterize the rheological behavior of resin-composites using different rheometer setups\(^15,18\). This also explained why rapid, light tapping of the placed resin-composite on the restored site gave better adaptation of material with cavity walls\(^10\).

For the irregular filler resin-composites, overall there was a decrease in the \(F_p\) with the repeated compression, which was again due to the settling of the filler particles after each compression (Fig. 5). But this decrease was not that significant as compared to the spherical filler resin-composite. This might be due to that irregular morphology of the filler particles resulted in more interlocking of particles resulting in more elasticity of the material. This result was in an agreement with another study by Lee et al.\(^10\). However, the change in temperature showed a less effect on packability of irregular filler particle resin-composites as compared to spherical filler particle resin-composite. That might be due to the reason that at higher temperature viscosity of the resin part of the resin-composite decreased, but the irregular filler morphology resulted in interlocking between filler particles and did not allow the fast settling of the filler part of the resin-composite.

As far as the effect of increase in speed of the compressive cycle was concerned, this increase had a very low effect on the packability of the resin-composite. This again was due to the irregular morphology of the resin-composite.

Similarly, in the case of the multimodal resin-composites an increase in compressive cycle speed and temperature had a low effect on the packability of the resin-composites. That might be due to the presence of multiple sizes of filler particles which resulted in more compact packing of filler particles and resulting in fewer spaces for further settling of filler particles under a cyclic compressive force.

In the present study, only a microscopic interpretation of the effect of the component of the composite, i.e. filler shape, size and interaction of these with resin system at different temperatures and compressive cycle’s speeds were studied. Effect of the monomer type and use of different coupling agents can be an area of further investigation. This methodology is a simple way of analyzing the rheological properties.
of commercial and experimental resin-composites in relation to their composition and chemistry.

CONCLUSION

All four variables did affect packability of the experimental composites, however the change in filler morphology has more effect as compared to all other variables. This study also showed the clinical relevance of rapid, light tapping of the placed resin-composite on the restored site gave better adaptation of material with cavity walls, which was due to the less recovery time of the adopted material, but this effect was not that significant in the case of the irregular filler particles

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