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# Optimum Sliding Wear Parameters for Minimum Volumetric Wear of Silica Filled Resin Based Dental Composites

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In this study, BisGMA and TEGDMA as monomers were used to fabricate dental composites. Camphorquinone was used for photopolymerization using LED light curing unit. To prepare filled resin based dental composites, different wt. % (5, 10, 15, and 20) of nanosilica were used. Unfilled and filled samples were prepared to test for volumetric wear. To access the effect of filler content, normal load, sliding velocity and number of cycles using $L_{25}$ orthogonal array, wear tests were performed on pin-on-disc apparatus using different levels of process parameters. Using Taguchi methodology and ANOVA, volumetric wear is analyzed, and it is revealed that the filler content is the most significant parameter which affects volumetric wear of nanosilica filled dental composites.

**Keywords:** Dental composite, Silica, Filler content, Taguchi, Volumetric wear.

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## 1. INTRODUCTION

Human tooth can be damaged due to caries, accident, and wrong brushing habits [1]. For the restoration of tooth, resin based dental composites (RBDCs) are generally used nowadays due to their tooth-like appearance. But polymerization shrinkage and mechanical properties of RBDCs are of great concern for researchers. RBDCs are generally comprised of BisGMA, UDMA, TEGDMA as resin monomers. BisGMA is highly viscous and hence not easy to handle. TEGDMA is used as a diluent to fabricate dental composites [2]. Camphorquinone is most commonly used photoinitiator which is yellowish in color [3]. During the light curing process, its color disappears and hence it is appropriate to use it for photopolymerization. Various ceramic particles have been used as fillers to improve mechanical properties of RBDCs [4]. Pratap et al. [5] used silica particles to study the void content and water sorption of RBDCs. In another study, nanoalumina filled dental composites were studied for compressive strength and microhardness. Socratis Thomaidis [6] et al. studied the mechanical properties of composite resins and their mutual interactions. Different formations were studied for mechanical properties. Saeed Beigi [7] et al. studied ternary thiol-ene-methacrylate systems along with BisGMA/TEGDMA and investigated mechanical properties for dental composites. Photopolymerization was carried out using BD/CQ as a photoinitiator. It was revealed that fracture toughness improved using ternary thiol-ene-methacrylate systems. Shiv et al. [8] analyzed silane treated nanosilica particles to prepare RBDCs. They studied polymerization shrinkage and thermo-mechanical properties of RBDCs. 3 wt. % nanosilica filled RBDCs showed better depth of cure and low polymerization shrinkage.

Many studies have been carried out to study various ceramic filled RBDCs for physical properties such as polymerization shrinkage [9], void content [10], depth of cure [11], water sorption and solubility. Similarly, many researchers have studied mechanical properties such as compressive strength [10, 12], flexural strength, microhardness of various filled RBDCs. Human mouth is subjected to various oral conditions such as salivary environment, food slurry, liquids of different pH values etc. So, wear of restorative materials occurs due to mastication process in different oral conditions [13]. Various parameters such as filler content, normal load, sliding velocity and number of cycles affect volumetric wear of RBDCs. So, it is important to access the effect of these parameters on volumetric wear. Very few studies have been carried out for investigation of wear behavior of filled resin RBDCs. This study has been carried out to investigate the effect of filler content, normal load, sliding velocity and number of cycles on the volumetric wear of nanosilica filled RBDCs using Taguchi methodology [14]. Nanosilica is economical and easily available ceramic.

## 2. MATERIALS AND METHODS

### 2.1 Sample Preparation

70 wt. % of BisGMA (Esstech Inc, Essington, PA, USA) as the base monomer and 30 wt. % of TEGDMA (TCI, Japan) as a diluent monomer were utilized to prepare a monomer mixture solution. For proper mixing of monomers, the mixture solution was stirred using a magnetic stirrer for 2 h. Then, taking 0.2 wt. % of resin matrix, Camphorquinone (Spectrochem, Mumbai, India) was added as a photoinitiator. 0.8 wt. % of resin matrix, DMAEMA was used as a coinitiator. Nanosilica (XF Nano, China) was added in different mixture solutions to prepare filled RBDCs of different filler content. Again, the solution was stirred for 2 h to achieve uniform dispersion of all ingredients. Resin-filler mixtures were poured in glass molds for sample preparation. Samples were stored in the refrigerator at a constant

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temperature of 4 °C for 24 h. Then, samples were kept at room temperature for 2 h. After that, filled and unfilled samples were light cured using LED LCU (1200 mW/cm$^2$, 450 to 490 nm, Dentmark, Mumbai, India). Different compositions of nanosilica filled dental composites prepared are shown in Table 1.

### 2.2 Volumetric Wear Measurement

To access the effect of filler content, normal load, sliding velocity and number of cycles on the volumetric wear of unfilled and filled RBDCs, Taguchi methodology was utilized. Filler content, normal load, sliding velocity and number of cycles were taken as process parameters of sliding wear test on pin-on-disc apparatus.

**Table 1** – Composition of aluminium oxide filled dental composites

| Sample Designation | Composition |
|---|---|
| RBDC-0 | Resin matrix only |
| RBDC-5 | Resin + Nanosilica Filler (5 %) |
| RBDC-10 | Resin + Nanosilica Filler (10 %) |
| RBDC-15 | Resin + Nanosilica Filler (15 %) |
| RBDC-20 | Resin + Nanosilica Filler (20 %) |

Different levels of filler content, normal load, sliding velocity and number of cycles taken in this study are shown in Table 2. As per L25 orthogonal array, wear tests were carried out to measure the volumetric wear of RBDCs.

**Table 2** – Levels of wear conditions

| Level | Factors | | | |
|---|---|---|---|---|
| | Filler loading (%) | Normal load (N) | Sliding velocity (m/s) | Number of cycles |
| 1 | 0 | 20 | 2 | 3000 |
| 2 | 5 | 40 | 4 | 6000 |
| 3 | 10 | 60 | 6 | 9000 |
| 4 | 15 | 80 | 8 | 12000 |
| 5 | 20 | 100 | 10 | 15000 |

The volumetric wear is measured using the following equation:

$$\Delta V = \frac{\Delta m}{\rho},$$

where $\Delta V$ is the volumetric wear in mm$^3$, $\Delta m$ is the mass lost due to wear in $g$, and $\rho$ is the density of test samples.

### 2.3 Experimental Results

As per L25 orthogonal array, 25 samples were tested to measure the volumetric wear of RBDcs.

Table 3 shows the design matrix and calculated volumetric wear of RBDCs. These results were analyzed using Taguchi method, and the optimum levels of process parameters were determined for minimum volumetric wear of nanosilica filled RBDCs. To check the significance of the model, analysis of variance test (ANOVA) was carried out. Significance level of 0.05 or confidence level of 95 % were taken for ANOVA analysis. ANOVA table for volumetric wear is shown in Table 4. From the ANOVA analysis it can be seen that "Prob. > F" value for filler content is less than 0.05 and hence the most significant parameter for volumetric wear behavior of RBDCs. Maximum and minimum values of the volumetric wear at different parameters of wear test of RBDCs are shown in Table 5.

**Table 3** – Experimental results

| S. No. | Filler content (%) | Normal load (N) | Sliding velocity (mm/s) | Number of cycles | Volumetric wear (mm$^3$) |
|---|---|---|---|---|---|
| 1 | 0 | 20 | 2 | 3000 | 0.0056 |
| 2 | 0 | 40 | 4 | 6000 | 0.0059 |
| 3 | 0 | 60 | 6 | 9000 | 0.0067 |
| 4 | 0 | 80 | 8 | 12000 | 0.0079 |
| 5 | 0 | 100 | 10 | 15000 | 0.0087 |
| 6 | 5 | 20 | 4 | 9000 | 0.0052 |
| 7 | 5 | 40 | 6 | 12000 | 0.0064 |
| 8 | 5 | 60 | 8 | 15000 | 0.0053 |
| 9 | 5 | 80 | 10 | 3000 | 0.0026 |
| 10 | 5 | 100 | 2 | 6000 | 0.0045 |
| 11 | 10 | 20 | 6 | 15000 | 0.0039 |
| 12 | 10 | 40 | 8 | 3000 | 0.0025 |
| 13 | 10 | 60 | 10 | 6000 | 0.0038 |
| 14 | 10 | 80 | 2 | 9000 | 0.0041 |
| 15 | 10 | 100 | 4 | 12000 | 0.0047 |
| 16 | 15 | 20 | 8 | 6000 | 0.0024 |
| 17 | 15 | 40 | 10 | 9000 | 0.0029 |
| 18 | 15 | 60 | 2 | 12000 | 0.0031 |
| 19 | 15 | 80 | 4 | 15000 | 0.0035 |
| 20 | 15 | 100 | 6 | 3000 | 0.0021 |
| 21 | 20 | 20 | 10 | 12000 | 0.0011 |
| 22 | 20 | 40 | 2 | 15000 | 0.0019 |
| 23 | 20 | 60 | 4 | 3000 | 0.0011 |
| 24 | 20 | 80 | 6 | 6000 | 0.0015 |
| 25 | 20 | 100 | 8 | 9000 | 0.0018 |

**Table 4** – ANOVA table

| Source | DF | Seq SS | Adj MS | F-value | P-value | Contribution |
|---|---|---|---|---|---|---|
| Filler loading (%) | 4 | 0.000086 | 0.000022 | 33.83 | 0 | 81.73 % |
| Normal load (N) | 4 | 0.000001 | 0 | 0.52 | 0.722 | 1.27 % |
| Sliding velocity (mm/s) | 4 | 0 | 0 | 0.15 | 0.96 | 0.35 % |
| Number of cycles | 4 | 0.000012 | 0.000003 | 4.89 | 0.27 | 11.82 % |
| Error | 8 | 0.000005 | 0.000001 | | | 4.83 % |
| Total | 24 | 0.000105 | | | | 100.0 % |

**Table 5** – Response table for volumetric wear

| Wear conditions | Levels | | | | | Max.-Min. (Δ) | Rank |
|---|---|---|---|---|---|---|---|
| | 1 | | | 4 | 5 | | |
| Filler loading (%) | 0.0069 | 0.0048 | 0.0038 | 0.0028 | 0.0015 | 0.0055 | 1 |
| Normal load (N) | 0.0036 | 0.0039 | 0.004 | 0.0039 | 0.0044 | 0.0007 | 3 |
| Sliding velocity (mm/s) | 0.0038 | 0.0041 | 0.0041 | 0.004 | 0.0038 | 0.0003 | 4 |
| Number of cycles | 0.0028 | 0.0036 | 0.0041 | 0.0046 | 0.0047 | 0.0019 | 2 |

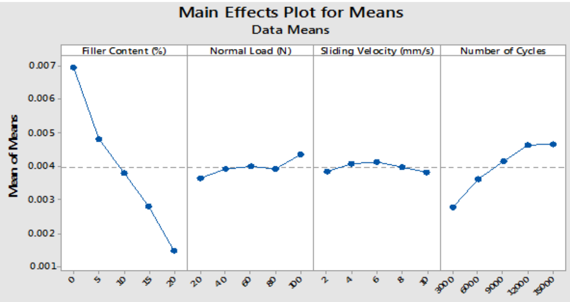


**Fig. 1** – Main effect plot for means of volumetric wear of RBDCs

The difference between the maximum and minimum values of volumetric wear at different parameters (Δ) gives the rank of factors affecting volumetric wear of RBDCs. It can be seen that filler loading affects the maximum as it has a maximum difference between the maximum and minimum values of volumetric wear at different parameters.

Fig. 1 shows the main effect plot for means of volumetric wear at different parameters of filler content, normal load, sliding velocity and number of cycles during the sliding wear test.

From the graph in Fig. 1, it can be seen that the volumetric wear decreases with an increase in the filler content from 0 to 20 wt. %, the minimum volumetric wear has been achieved at 20 % of nanosilica filler. For the normal load and sliding velocity, no significant variation can be seen in the graph. This indicates that normal load and sliding velocity do not affect volumetric wear significantly at different levels. Number of cycles also affects volumetric wear considerably. From the figure, it can be revealed that the volumetric wear increases considerably as the number of cycles increases from 3000 to 15000. The minimum volumetric wear has been found at 3000 cycles during the sliding wear test.

## 3. CONCLUSIONS

RBDCs are increasingly used for human dental restorations, hence it is quite important to study the wear behavior of RBDCs under different operating parameters. This study has been carried out to find the optimum operating parameters (filler content, normal load, sliding velocity and number of cycles) in volumetric wear tests for nanosilica filled RBDCs. From this study, the following conclusions have been obtained. Among filler content, normal load, sliding velocity and number of cycles, the filler content is an indicator of wear of nanosilica filled RBDCs. Results showed that the volumetric wear of dental composites decreases with increasing filler loading. The minimum volumetric wear was found at 20 % of nanosilica filled RBDCs.

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## Оптимальні параметри зносу при терті ковзання для мінімального об'ємного зносу стоматологічних композитів на основі смол, наповнених кремнеземом

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У дослідженні BisGMA та TEGDMA використовувались як мономери для виготовлення стоматологічних композитів. Камфорохінон застосовували для фотополімеризації з використанням світлодіодного фотополімеризатора. Для приготування стоматологічних композитів на основі наповнених смол використовували кремнезем з різними ваговими відсотками (5, 10, 15 та 20). Ненаповнені та наповнені зразки були підготовлені для випробувань на об'ємний знос. Щоб оцінити вплив вмісту наповнювача, нормального навантаження, швидкості ковзання та кількості циклів за допомогою ортогонального масиву $L_{25}$, випробування на знос проводили з використанням різних параметрів процесу. Об'ємний знос проаналізовано за допомогою методології Taguchi та ANOVA. Було виявлено, що вміст наповнювача є найбільш значущим параметром, який впливає на об'ємний знос стоматологічних композитів, наповнених кремнеземом.

**Ключові слова:** Стоматологічний композит, Кремнезем, Вміст наповнювача, Taguchi, Об'ємний знос.