Wear Behavior of Dental Composites

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Abstract— In this current study, three types of dental composites namely Tetric N-Ceram Ivoclar Vivadent, Coltene Brilliant NG and Voco Polofil NHT were comparatively evaluated on Pin on disc machine for wear rate analysis. The variables considered for the research work were Speed, load and sliding distance. Various combinations of these variables were made. Pre-experimentation was also carried to find out the most influencing values of these variables. The variables were so chosen that they would represent actual conditions under which the dental composites were supposed to work.The effect of three parameters such as Speed, load and sliding distance on Wear loss of three types of dental filler materials were examined. In this investigation, an effective approach based on Taguchi method, analysis of variance (ANOVA), multivariable linear regression (MVLR), has been developed to determine the optimum conditions leading to minimum Wear. Experiments were conducted by varying Speed, load and sliding distance using L9 orthogonal array of Taguchi method. After experimentation it was found that Tetric N-Ceram Ivoclar Vivadent has more sliding wear resistance as compare to Coltene Brilliant NG and Voco Polofil NHT dental composite.

Key words: Dental Filler Material, Wear rate, Taguchi, ANOVA

I. INTRODUCTION

Human teeth are not only an important masticatory organ but are also closely associated with both pronunciation and the facial aesthetics of human beings. Beyond all doubt, teeth play an extremely significant role in our daily life. With ageing, various pathological factors and traumas, tooth lesions such as caries, partial or overall tooth tissue loss will occur unavoidably. As a result, artificial dental materials have gradually been developed and used to restore and treat the lesions of human teeth. Nowadays, metals and alloys, ceramics and composite materials are most widely used for dental restorations and implants Tribology is the science of the mechanisms of friction, lubrication and wear of interacting surfaces that are in relative motion. By definition, friction is the rubbing of one object or surface against another, whilst wear is a process that occurs whenever a surface is exposed to another surface or to chemically active substances [1], which can result in a progressive removal of material from surfaces through mechanical or chemical action. In general, oral biomechanical functions can result in some tribological movement of teeth, restorations and implants occurring in the mouth [2]. For Author to whom any correspondence should be addressed. example, during chewing food, the teeth, together with any restorations, have to move in contact with one another, and then friction and wear occur generally with the lubrication of saliva or food slurry [3]. It has been accepted that tooth wear is a clinical problem that is becoming increasingly important in ageing populations. Understanding of dental friction and wear behaviour would help the clinical management of tooth wear, which involves the replacement of missing tooth tissue with dental materials, together with an attempt to minimize the causal factors and develop new dental materials [4].

In addition, tooth wear proceeds in a regular progressive manner, particularly in the molar teeth, endowing it with potential as a method of estimating the evolution, age, diet and health changes of ancient humans in archaeology [5].

Therefore tribology of dental materials has developed and is paid increasing attention by various researchersThe dental filler or restorative materials have to face various kinds of forces and stresses like chemical, thermal and mechanical [6]. The functions concerned with functional, biological and aesthetic aspects are greatly influenced by the excessive wear of teeth and restorative materials [7]. In this scenario, the wear rate becomes an area of concern as far as the restorative materials are concerned. The normal aging process is the major cause of tooth wear. Although, the entity of teeth is independent of the rate of tooth wear in most of the people [8]. This uncertain life-span of tooth leads to the use of dental restorative materials. The wear resistance and aesthetics of dental restorative materials have raised the interest in greater applications of resin composites [9]. Still their poor wear resistance limits their applications. The stress induced due to the abrasive action and occlusal loads during mastication are the major aspects of these limitations [10-11]. This current study gives the comparison of two types of dental restorative materials. The variables Speed, load and sliding distance represents the normal working conditions of the restorative materials. The varying load in the research work is the significance of the variable force a human tooth tolerates while chewing and biting. The chewing force is more for the harder food materials and less for the softer food materials. The composite must withstand both kinds of forces.

In view of the above, an attempt has been made, to understand dry sliding wear response of three types of dental filler materials over different Speed, load and sliding distance, subjected to identical test to undertake comparative study. The operating wear mechanisms causing material removal in all the cases have also been examine.

II. EXPERIMENTAL DETAILS

In this study, the settings of Wear parameters were determined by using taguchi experimental design method. Orthogonal arrays of taguchi, the Signal – to– Noise (S/N) ratio, the analysis of variance (ANOVA), and regression analysis are employed to analyze the effect of the Speed, load and sliding distance parameters on Wear. In order to analysis of Wear, experiments are carried out using L9 orthogonal array. For this purpose of three factors (Speed, load and sliding distance), each at three levels are taken into account as shown in Table 2.1.

Parameters	Levels I	Levels II	Levels III
Load (N)	10	20	30.
Speed (RPM)	200	300	400
Sliding Distance (M)	1000	2000	3000

Table 2.1. Process Parameters and their levels

A. *Experimental Set Up*

In the present research one of the commonest and simplest methods to test for wear rate was by using a pin-on-disc wear tester (Model: TR-20, DUCOM) as per ASTM: G99 – 05 as shown in Fig 2.1The counterpart disc was made of quenched and tempered alumina having a surface hardness of 74 HRC. In this study, three dental composites, Tetric N-Ceram Ivoclar Vivadent,Coltene Brilliant NG and Voco Polofil NHT are used for dry sliding wear analysis. The materials were extruded directly into a cylindrical Teflon Mold and Cover with a microscope cover glass to minimize contact with oxygen. They were photo -cured by irradiating the specimen from both ends for 5 min to ensure that the maximum possible extent of curing was reached. They were then stored in water at 37 C. for a week before testing. A Cylindrical specimen with a diameter of approximately 6mm and Length 20 mm was used as the pin. The diameter of the specimen was chosen to be comparable in area to that of a human tooth.While trying to minimize the edge effect by using the largest possible diameter.

The wear losses of sample pins were recorded using an electronic microbalance having an accuracy of ± 0.0001gm. After wear test specimens were cleaned thoroughly and weighed again. The wear rate was calculated by a weight-loss method

$\Delta W = (w1 - w2)$ ------------------------------ (1.1)

Where, ΔW = Weight loss of the specimen (gm)

w1 = Weight loss of the specimen before test

w2 = Weight loss of the specimen after test

Fig. 2.1: Experimental setup

OVAT analysis were performed by varying one process parameter from lower to higher value by keeping all other process parameter constant, and measure the effect on quality characteristic. By performing OVAT analysis it is found that Speed, load and sliding distance are influencing parameters for Wear. According to OVAT analysis following input parameters namely Speed, load and sliding distance are selected with their Levels.

Trial no	Load (N)	Speed (RPM)	Sliding Distance (M)
1	10	200	1000
2	10	300	2000
3	10	400	3000
4	20	200	2000
5	20	300	3000
6	20	400	1000
7	30	200	3000
8	30	300	1000
9	30	400	2000

Table 2.2. L9 orthogonal array

III. ANALYSIS OF EXPERIMENTAL RESULTS AND DISCUSSION

Trial no	Load (N)	Speed (RPM)	Sliding Distance (M)	C1 Avg.Wear	C2 Avg.Wear	C3 Avg.Wear
1	10	200	1000	0.0042	0.0061	0.0067
2	10	300	2000	0.0064	0.0096	0.0102
3	10	400	3000	0.0094	0.014	0.0151
4	20	200	2000	0.0067	0.0101	0.0107
5	20	300	3000	0.0091	0.0146	0.0145
6	20	400	1000	0.0076	0.0111	0.0121
7	30	200	3000	0.0106	0.0156	0.0161
8	30	300	1000	0.0086	0.0129	0.0137
9	30	400	2000	0.0116	0.0164	0.0185

Table 3.1. Summary Report for Different trials Conducted during Experimentation

A. *S/N Ratio Analysis*

In the Taguchi method, the term ‘signal’ represents the desirable value (mean) for the output characteristic and the term ‘noise’ represents the undesirable value for the output characteristic. Taguchi uses the S/N ratio to measure the quality characteristic deviating from the desired value. There are several S/N ratios available depending on type of characteristic: lower is better (LB), nominal is best (NB), or larger is better (HB). Larger is better S/N ratio used here. Smaller -the-better quality characteristic was implemented and introduced in this study.

For the for Smaller the better characteristic

$$S/N = -10 \log10 (MSDLB)$$

Where MSD= Mean Squared Division

The mean square deviation (MSD) is a statistical quality that reflects the deviation from the target value. The expressions for MSD are different for different quality characteristics. For the ‘nominal is best’ characteristics, the standard definition of MSD is used. For the other two characteristics the definition is slightly modified. For ‘smaller is better’, the unstated target value is zero. For ‘larger is better’,the inverse of each large value becomes a small value and again, the unstated target value is zero. Thus for all three expression, the smallest magnitude of MSD is being sought.

MSD = (Y12 + Y22 +Y32+…………..)/n -------- (3.1)

Where Y1, Y2, Y3 are the responses and n is the number of tests in a trial and MSD is the target value of the result. The level of a factor with the highest S/N ratio was the optimum level for responses measured. Table No 3.2, 3.3 and Figure 3.1, 3.2 depict the factor effect on Wear rate. The larger the signal to noise ratio the more favorable is the effect of the input variable on the output

Term	Coef	SE Coef	T	P
Constant	42.0161	0.1744	240.943	0.000
LOAD (N) 10	1.9668	0.2466	7.975	0.015
LOAD (N) 20	0.2110	0.2466	0.856	0.482
SPEED(RP 200	1.4864	0.2466	6.027	0.026
SPEED(RP 300	-0.0142	0.2466	-0.058	0.959
S.Dist(M 1000	1.7268	0.2466	7.002	0.020
S.Dist(M 2000	0.0058	0.2466	0.024	0.983

Table 3.2. Estimated Model Coefficients for SN ratios for Tetric N Ceram Ivoclar Vivadent

Summary of Model
S = 0.5231 R-Sq = 99.0% R-Sq(adj) = 96.2%

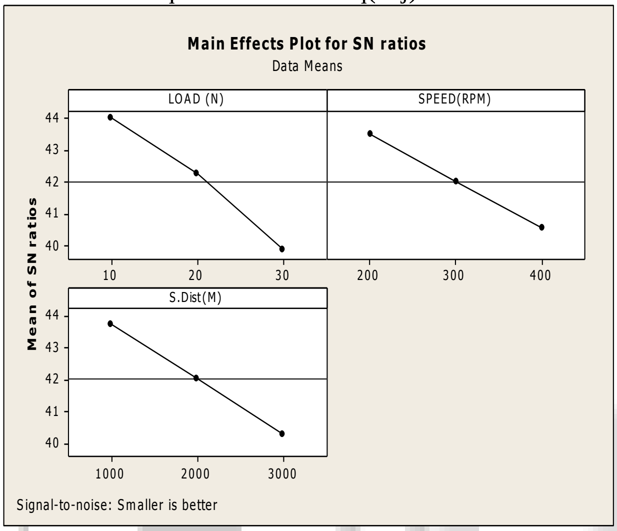

Fig. 3.1: Effect of process parameters on S/N Ratio Tetric N Ceram Ivoclar Vivadent

From the Table 3.2 and Figure 3.1 it is clear that, the optimum value levels for miminum Wear are at Speed (200) Load (10 N) and sliding distance (1000 meter). Also, for Wear rate, from it can be seen that, the most significant factor is Load (A), followed by sliding distance (B) and Speed (C).

Term	Coef	SECoef	T	P
Constant	38.5638	0.1866	206.695	0.000
Load(N) 10	2.0113	0.2639	7.623	0.017
Load(N) 20	0.0095	0.2639	0.036	0.974
Speed(rpm) 200	1.5510	0.2639	5.878	0.028
Speed(rpm) 300	-0.2786	0.2639	-1.056	0.402
Sliding 1000	1.8279	0.2639	6.928	0.020
Sliding 2000	0.0933	0.2639	0.354	0.757

Table 3.3. Estimated Model Coefficients for SN ratios for Coltene Brilliant NG

Summary of Model
S =0.5597 R-Sq = 98.9% R-Sq(adj) = 95.7%

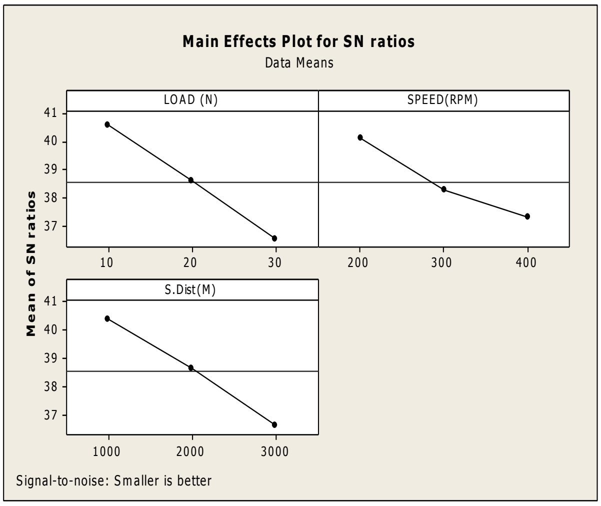

Fig. 3.2: Effect of process parameters on S/N Ratio for Coltene Brilliant NG

From the Table 3.3 and Figure 3.2 it is clear that, the optimum value levels for minimum Wear for Coltene Brilliant NG are at Speed (200) Load (10 N) and sliding distance (1000 meter). Also, for Wear rate, from it can be seen that, the most significant factor is Load (A), followed by sliding distance (B) and Speed (C).

Term	Coef	SECoef	T	P
Constant	38.0047	0.1741	218.240	0.000
LOAD(N) 10	1.9043	0.2463	7.733	0.016
LOAD(N) 20 0.2463	0.1718	0.2463	0.697	0.558
SPEED(RP 200	1.5801	0.2463	6.416	0.023
SPEED(RP 3000	-0.0492	0.2463	-0.200	.860
S.Dist(M 1000	1.6915	0.2463	6.868	0.021
S.Dist(M 2000	-0.0390	0.2463	-0.158	0.889

Table 3.4. Estimated Model Coefficients for SN ratios for Voco Polfil NHT

Summary of Model
S = 0.5224 R-Sq = 99.0% R-Sq(adj) = 96.1%

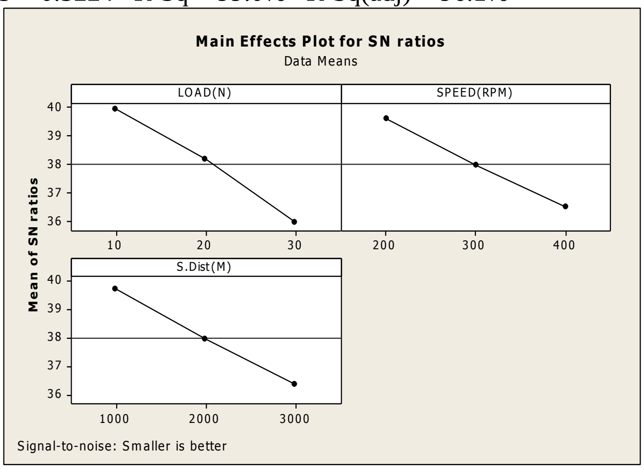

Fig. 3.3: Effect of process parameters on S/N Ratio for Voco Polfil NHT

From the Table 3.4 and Figure 3.3 it is clear that, the optimum value levels for minimum Wear for Coltene Brilliant NG are at Speed (200) Load (10 N) and sliding distance (1000 meter). Also, for Wear rate, from it can be seen that, the most significant factor is Load (A), followed by sliding distance (B) and Speed (C).

B. *Analysis Of Variance (ANOVA)*

Analysis of variance is a standard statistical technique to interpret experimental results. It is extensively used to detect differences in average performance of groups of items under investigation. It breaks down the variation in the experimental result into accountable sources and thus finds the parameters whose contribution to total variation is significant. Thus analysis of variance is used to study the relative influences of multiple variables, and their significance The purpose of ANOVA is to investigate which process parameters significantly affect the quality characteristic. The analysis of the experimental data is carried out using the software MINITAB 17 specially used for design of experiment applications. In order to find out statistical Significance of various factors like Speed (A), Load (B), and Sliding Distance (C), and their interactions on Wear, analysis of variance (ANOVA) is performed on experimental data. Table 3.5, 3.6 & Table 3.7 shows the result of the ANOVA with the Wear. The last column of the table indicates p-value for the individual control factors.

Source	DF	Seq SS	Adj MS	F	P
LOAD (N)	2	0.000020	0.000010	1306.86	0.001
SPEED(RPM)	2	0.000009	0.000004	553.00	0.002
S.Dist(M)	2	0.000013	0.000006	811.00	0.001
Residual Error	2	0.000001	0.000001		0005
Total	8	0.000043			

Table 3.5. ANOVA RESULTS for Tetric N Ceram Ivoclar Vivadent

It is known that smaller the p-value, greater the significance of the factor. The ANOVA table for S/N ratio (Table 3.4) indicates that (1) Load, (2) Sliding distance and (3) Speed has the influence on the wear of the Tetric N Ceram Ivoclar Vivadent. The last column in Table 3.5 shows the percentage contribution of each factor on total variation indicating their degree of influence on the result. One can observe from the ANOVA table that the Load (46.51%), Sliding distance (30.23%) and Speed (20.93) has great influence on the wear. It means, the Load is the most significant factor.

Source	DF	Seq SS	Adj MS	F	P
LOAD (N)	2	0.000039	0.000020	307.95	0.003
SPEED(RPM)	2	0.000016	0.000008	124.16	0.008
S.Dist(M)	2	0.000033	0.000017	263.53	0.004
Residual Error	2	0.000003	0.0000015		
Total	8	0.000091			

Table 3.6. ANOVA RESULTS for Coltene Brilliant NG

One can observe from the ANOVA table that the Load (42.86%), Sliding distance (36.86%) and Speed (17.58) has great influence on the wear. It means, the Load is the most significant factor for the wear of Coltene Brilliant NG.

Source	DF	Seq SS	Adj MS	F	P
LOAD (N)	2	0.000046	0.000023	141.08	0.007
SPEED(RPM)	2	0.000025	0.000013	76.92	0.013
S.Dist(M)	2	0.000029	0.000015	88.96	0.011
Residual Error	2	0.000004	0.000002		
Total	8	0.000104			

Table 3.7. ANOVA RESULTS for Voco Polfil NHT

One can observe from the ANOVA table that the Load (44.23%), Sliding distance (27.88%) and Speed (24.04%) has great influence on the wear. It means, the Load is the most significant factor for the wear of Voco Polfil NHT

C. *Regression Analysis*

The Speed, load and sliding distance are considered in the development of mathematical models for wear analysis. The correlation between the considered wear parameters are obtained by linear regression. The linear polynomial models are developed using commercially available Minitab 17 software for various wear parameters and are listed as below:

The regression equation for Tetric N Ceram Ivoclar Vivadent

Wear(Gm) = - 0.00181 + 0.000180 LOAD (N) + 0.000012 SPEED(RPM)+ 0.000001 S.Dist(M)—3.2

Sample Calculation

As per my trial take trail no 1 reading for Tetric N Ceram Ivoclar

Put this values in equation 3.2

Yopt =- 0.00181 + 0.000180 *10 + 0.000012 *200 + 0.000001*1000

Yopt = 0.0034 (predicted by regression)

The regression equation for Coltene Brilliant NG

Wear (Gm) = - 0.00235 + 0.000253 LOAD (N) + 0.000016 SPEED(RPM) + 0.000002 S.Dist(M) –3.3

As per my trial take trail no 1 reading for Coltene Brilliant NG sample Calculation

Put this values in equation 3.3

Yopt= - 0.00235 + 0.000253 *10 + 0.000016*200 + 0.000016 *1000

Yopt = 0.0053 (predicted by regression)

Similarly remaining trial values are calculated.

The regression equation for Voco Polfil NHT

Wear(Gm) = - 0.00287 + 0.000272 LOAD (N) + 0.000020 SPEED(RPM) + 0.000002 S.Dist(M)---3.4

As per my trial take trail no 1 reading for Voco Polfil NHT sample Calculation

Put this values in equation 3.4

Yopt= - 0.00287 + 0.000272 *10 + 0.000020*200 + 0.000020 *1000

Yopt = 0.0058 (predicted by regression)

Similary remaining trial values are calculated

D. Analysis Of S/N Ratio

In the taguchi method, the term signal represents the desirable value (mean) for the output characteristic and the term noise represents the undesirable value (deviation, SD) for the output characteristic. Therefore the S/N ratio is the ratio of the mean to the SD. Taguchi uses the S/N ratio to measure the quality characteristic deviating from the desired value. There are several S/N ratios available, depending on the type of the characteristic Taguchi recommends analyzing the mean response for each run in the inner array, and he also suggests analyzing variation using an appropriately chosen signal-to-noise ratio (S/N).[10]

These S/N ratios are derived from the quadratic loss function and three of them (Equ. (3.5)– (3.6)) are considered to be standard and widely applicable.

S/N=10log Y2/S2 ----------------- (3.5)

S/N=-10log (1/n∑1/y2) ------------------- (3.6)

S/N=-log1/n (∑1/y2) ----------------- (3.7)

Where y, is the average of observed data, S2 is the Variance of y, n is the number of observations and y is the observed data. Using the above-presented data with the selected above formula for calculating S/N, the Taguchi experiment results are summarized in Table 3.7, 3.8 and presented in Fig.3.1, 3.2 which are obtained by means of MINITAB 17 statistical software. Response for Signal to Noise Ratios Smaller is better.

E. Analysis Of Variance (ANOVA)

The analysis of variance (ANOVA) establishes the relative significance of factors in terms of their percentage contribution to the response (Phadke, 1989; Ross, 1996) The ANOVA is also needed for estimating the variance of error for the effects and the confidence interval of the prediction error. The analysis is performed on S/N ratios to obtain the percentage contribution of each of the factors.DoF: Degree of freedom, SS: Sum of squares, %c: Percent contribution, #: 95% confidence interval

IV. CONCLUSIONS

The Taguchi method was applied to find an optimal setting of the Wear analysis. The result from the Taguchi method chooses an optimal solution from combinations of factors if it gives maximized normalized combined S/N ratio of targeted outputs. The L-9 OA was used to accommodate three control factors and each with 3 levels for experimental plan selected process parameters are Speed, Load and Sliding Distance. The results are summarized as follows:

- From the analysis, it is clear that the three process parameter Speed, Load and Sliding Distance have significant effect on Wear.
- The Optimal level of process parameter was found to be A1B1C1.
- The prediction made by Taguchi parameter design technique is in good agreement with confirmation results
- The result of present investigation are valid within specified range of process parameters
- The Wear is highly influenced by load factor for all three dental composite materials.
- Tetric N Ceram Ivoclar Vivadent dental composite has excellent wear resistance as compare to Coltene Brilliant NG and Voco Polfil NHT
- Coltene Brilliant NG and Voco Polfil NHT have more wear as compare to Tetric N Ceram Ivoclar Vivadent dental composite.
- So finally from wear test it is concluded that Tetric N Ceram Ivoclar Vivadent dental composite is best for dental composite.
- Also the prediction made by Regression Analysis is in good agreement with Confirmation results.

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REFERENCES

[1] Heintze S D, Zappini G and Rousson V 2005 Wear of ten dental restorative materials in five simulators-results of a round robin test Dental Mater. 21 304–17

[2] Powers J and Bayne S C 1988 Friction and wear of dental materials ASM Handbook, vol 18, Friction, Lubrication and Wear Technology (Metals Park, OH: ASTM) pp 666–81

[3] Mair L H, Strlarski T A, Vowles R W and Loyd C H 1996 Wear: mechanisms, manifestations and measurement Report of a workshop J. Dentistry 24 141–8

[4] Oh W, Delong R and Anusavice K J 2002 Factors affecting enamel and ceramic wear: a literature review J. Prosthetic Dentistry 87 451–9

[5] Mair L H 1992 Wear in dentistry—current terminology J. Dentistry 20 140–4

[6] Craig's Restorative Dental Materials, 13th edition, edited by Ronald L. Sakaguchi, DDS, MS, PhD, MBA and John M. Powers, PhD.

[7] Kevin H.-K. Yip, BDS, MEd, MMedSc., PhD/ Roger J. Smales, MDS, DDS/ John A. Kaidonis, BDS, BScDent, PhD, "Differential Wear of Teeth and Restorative Materials: Clinical Implications'', The International Journal of Prosthodontics, Volume 17, Number 3, 2004.

[8] David Bartlett, BDS, PhD, FDS RCS, "A new look at erosive tooth wear in elderly people", JADA, Vol. 138, September 2007.

[9] Peter M. Marquis, BSc, FIM, PhD/ Xiaoqiang Hu, BEng, MEng, PhD/ Adrian C. Shortall, DDS, BDS, FDS, FFD, "Two-Body wear of Dental Composites under Different Loads," Volume 13, Number 6, 2000, The International Journal of Prosthodontics.

[10] Freilich MA, Goldberg AJ, Gilpatrick RO, Simonsen RJ, "Three year occlusal wear of posterior composites", Dent Mater 1992;8: 224–228.

[11] Johnson GH, Bales DJ, Gordon GE, Powell LV, "Clinical performance of dental composite resin", Quintessence Int 1992;23: 705–711.