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Filler particle size and composite resin classification systems

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Summary

The currently used composite resin classification systems need review if they are to continue to serve as descriptives and quantitative parameters denoting the filler particle content of these materials. Examination of the particles in 12 composite resins using a technique of washing the filler particles from the matrix of the composite resin was presented as yet another method of grouping composites according to filler particle content. Light microscopic examination of the filler particles that remained provided a separation of the 12 materials into four easily distinguished groups based on filler particle sizes. The wear of the 12 composite resins determined in a previous study was examined in relation to the classification of the materials by the currently available systems. The wear values were also examined using the groupings of the materials according to their filler particle sizes as determined by separating the particles from the matrix by the washing technique. Grouping composites on the basis of the filler particle sizes found after washing was easily correlated with wear and supported the suggestion that composites with smaller filler particles wear less.

Introduction

Ever since Dr Raphael Bowen (1962) introduced composite resins to the profession, clinicians, researchers, and manufacturers have sought ways to describe and communicate about these materials. The first classification system was one introduced by Lutz and Phillips (1983) and was based on the average size of the filler particles, manufacturing techniques, and the chemical composition of the filler particles. Since then, other systems have been suggested by Leinfelder (1989), Roulet (1987), Marshall, Marshall & Bayne (1988), and most recently Hosada *et al.* (1990).

Composite classification systems

The basis for the Lutz and Phillips (1983) system rests with three types of fillers organized into four major classes. The three types of filler particles are: 1) traditional macrofillers; 2) microfillers (pyrogenic silica), and 3) microfiller-based complexes, with three subgroups, namely: a) splintered pre-polymerized microfilled complexes (SPP); b) spherical polymer-based microfilled complexes (SphPB), and c) the agglomerated microfiller complexes (AMC). The four composite resin classes based on these types of fillers were: 1) traditional composite resins, 2) hybrid composite resins, 3) homogeneous microfilled composite resins, and 4) heterogeneous microfilled composite resins. The heterogeneous group was further subdivided into three groups: a) splintered

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pre-polymerized particles; b) spherical pre-polymerized particles, and c) agglomerated microfiller complexes.

The classification system by Roulet (1987) is very similar to the Lutz and Phillips (1983) system, differing only in the number of composite classes. Roulet (1987) suggested four classes, namely: 1) traditional composites (TC); 2) hybrid composites (HC); 3) homogeneous microfilled composites (HMC), and 4) inhomogeneous microfilled composites (IMC). The IMC group was further subdivided into three groups: a) splintered pre-polymerized particles (IMC + SPP); b) spherical polymer-based microfilled complexes (IMC + SphPB), and c) agglomerated microfiller complexes (IMC + AMC). Leinfelder (1989) proposed a classification system using five major categories: 1) large particle (conventional); 2) intermediate; 3) fine particle; 4) microfilled, and 5) hybrids or blends.

Marshall *et al.* (1988) classifying composite resins by: 1) the amount of filler by weight and volume subdivided into unfilled resins, microfills, hybrids for anterior restorations, macrofills, midifills, and hybrids for posterior restorations; 2) the filler particle size subdivided into macrofill, midifill, minifill, microfill, and hybrid, and 3) the method of filler addition subdivided into: a) homogeneous filler; (midifill, microfill, and hybrids), or b) heterogeneous filler (microfill and hybrid).

The system by Hosada *et al.* (1990) consisted of five primary groups and two hypothetical categories. The two hypothetical groups were based on filler particle shape and distribution. The five classes were: 1) traditional composite resins; 2) microfilled (MFR); 3) microfilled type (MFR); 4) hybrid, and 5) semihybrid or heavily-filled.

The most common element in the five systems is the nomenclature in the systems. For example, the terms traditional, microfill, fine particle, hybrid, etc., are used in a number of the systems, yet the descriptions or quantitative parameters for these terms are different from system to system. Examples of quantitative parameters and descriptives used in the several systems are the sizes of the filler particles, and the different manufacturing processes to produce the filler particles. A critical examination of the descriptives and quantitative parameters used to describe the common terms for the several systems clearly demonstrate some major differences as well as some of the confusion that has resulted.

Common descriptives and/or quantitative parameters

Traditional composite resins. Traditional composite resins are described as containing traditional (Lutz & Phillips, 1983; Roulet, 1987; Hosada *et al.*, 1990) or conventional (Bowen, 1962; Leinfelder, 1989) macrofiller particles which are mechanically ground or crushed from larger pieces of purely inorganic materials such as quartz, glass, borosilicate, or a ceramic. This process results in the particles taking on a splinter or irregular shape, producing sizes ranging from 0·1 to 100 μm (Lutz & Phillips, 1983). The lower size limit (5–30 μm) is the direct result of the manufacturing process. Milling at the present time cannot produce particles smaller than 0·1 μm (Lutz & Phillips, 1983). Inorganic fillers larger than 100 μm are highly visible in the composite. In recent years even smaller, softer, and more rounded macrofiller particles (1–5 μm) have been incorporated into the traditional composites (Lutz & Phillips, 1983). Interestingly, the particle size for this group of composite resins has also been reported as 20–50 μm (Leinfelder, 1989), and 30–59 μm (Leinfelder, 1991), as well as 5–40 μm in yet another publication (Bowen, 1962). It has also been suggested that this class of composites be further divided into groups with an average particle sizes greater than 10 μm, less than 10 μm, and less than 5 μm (Roulet, 1987).

Intermediate composite resins. The intermediate (Leinfelder, 1989; 1991) composite resins have filler particles ranging in size from 1–5 μm. The size distribution permits maximum filler loading, as compared to the microfilled composites, which generally are considerably less filled. One is uncertain, but perhaps composite resins classified as intermediate, may also be called traditional composites with the smaller filler particles by one of the other systems. The midifill composits may also be considered within this class, however one cannot be certain. The midifill (Marshall *et al.*, 1988) have an average particle size of 4 μm with a range of 1–10 μm. However, they would fit the average size and range distribution of the traditional composites as well.

Fine particle composite resins. The fine particle composite resins contain fillers that average 0·5–1·0 μm (Leinfelder, 1989; 1991). The minifill (Marshall *et al.*, 1988) composites may also be grouped with the fine particle composites.

Hybrids or blend composite resins. A composite resin classified as a hybrid or blend (Leinfelder, 1989) contains colloidal silica particles in addition to the larger filler particles. Colloidal silica particles are produced by burning silicon tetrachloride in a mixture of hydrogen and oxygen gas, which produces colloidal silicon dioxide, also called pyrogenic particles. Such particles can also be made by allowing colloidal particles of sodium silicate to react with hydrochloric acid to form silicon dioxide and sodium chloride. With these techniques, filler particles just a few hundred nanometers in diameter can be made (Soderholm, 1985). Unfortunately, there is no general agreement as to how much colloidal silica filler particles should be present to classify a composite as a hybrid. It has been suggested that the submicron filler should constitute at least 20–25% by weight of the actual filler content (Leinfelder, 1989). The newest hybrids contain particles with an average size of 0·8–1·0 μm (Roulet, 1987). Interestingly, nearly all composite resins on the market contain submicron-sized particles. Even composite resins that are classified as conventional or intermediate contain several percent (Leinfelder, 1989).

Microfiller composite resins. Microfiller particles are finely dispersed radiolucent glass spheres created chemically by hydrolysis and precipitation. Originally, the average size of these filler particles was 0·04 μm (Bowen, 1962) or 0·05 μm (Lutz & Phillips, 1983; Leinfelder, 1989), and even more recently 0·04–0·06 μm (Leinfelder, 1991) depending on the publication. The tendency recently has been to use larger particles in the range of 0·05–0·1 μm (Lutz & Phillips, 1983). The microfilled composite resins contain pyrogenic or colloidal silica and the particle size ranges between 0·001 and 0·1 μm. The dispersion is colloidal, therefore, any particle smaller than 0·1 μm are colloidally dispersed (Lutz & Phillips, 1983). Because the particles are extremely small, the filler loading for this class of composites is lower than either the conventional or intermediate composite resins. For example, the filler loading for the intermediate composites may exceed 85% by weight, while the loading is generally 50–65% for microfilled composite resins.

Since the surface area-to-volume ratio of the colloidal silica particles is quite high, it is difficult if not impossible to attain the higher level of loading in composites containing larger fillers (Leinfelder, 1989). In order to maximize loading, a special process is used in filler preparation. First, sufficient amounts of colloidal silica filler particles are added to the resin matrix. The filled resin is then polymerized and subsequently ground into small particles. The size of these filled polymerized particles approximate

20–50 μm (Leinfelder, 1989). These particles are then incorporated into a resin matrix already filled with the submicron fillers. Regardless of the process, the filler content of microfilled filler particles is limited to 35–50% (Bowen, 1962), or 50–65% (Leinfelder, 1989), by weight (depending on the author cited), as compared to 75–80% in conventional composite resins.

Homogeneous microfilled composite resins. Composite resins in this class are combinations of an organic matrix and directly admixed microfiller particles. It has been suggested that the homogeneity and the extremely small particle size provide superior wear properties. However, the inorganic loading with such small particles (0·04–0·2 μm) is still limited because of their large surface area (Lutz & Phillips, 1983; Roulet, 1987).

Heterogeneous microfilled composite resins. Heterogeneous (Lutz & Phillips, 1983) or inhomogeneous (Roulet, 1987) microfilled composite resins are combinations of an organic matrix, directly admixed microfilled particles, and microfiller-based complexes. Heterogeneous microfilled composite resins are further subdivided into three groups to attain maximum inorganic loading with microfiller particles. The three different types are: a) splintered pre-polymerized microfilled complexes; b) spherical polymer-based microfilled complexes, and c) agglomerated microfilled complexes (Lutz & Phillips, 1983).

Splintered pre-polymerized microfilled complexes (SPP). These composite resins consist of pre-polymerized milled particles incorporated within the composite resin by a specific process. The filler particles are initially pyrogenic silica combined with a resin matrix. The mixture is heat cured and then milled into particles that are large in size, ranging from 1–200 μm (Lutz & Phillips, 1983; Roulet, 1987). Since these particles contain inorganic SiO_2 they are actually 'filled fillers' thus the term 'splintered pre-polymerized microfilled complexes'.

Spherical polymer-based microfilled complex (SphPB). These composite resins (SphPBs) are manufactured by incorporating pyrogenic silica filler particles into a diacrylate-PMMA mixture. Following suspension polymerization (partially cured), spheres with an average diameter of 20–30 μm are obtained (Lutz & Phillips, 1983; Roulet, 1987). The spheres are densely packed through sophisticated size distributions and manufacturing techniques within the composite resins.

Agglomerated microfiller complexes (AMC). Agglomerated microfiller complexes consist of artificially agglomerated (gathered into a cluster shape) filler particles which have a size of 1–100 nanometers and are obtained by either hydrolysis or precipitation techniques or some other special procedure (Lutz & Phillips, 1983). This process always includes a heat treatment at 600°C, which agglomerates the primary filler particles to purely inorganic secondary particles having a particle size of 0·5–50 μm (Roulet, 1987).

Applying the classification system

The utility of any composite resin classification system by the practising professional and/or the research community is being able to apply the descriptive and quantitative parameters to any composite materials and readily separate them into some organized format. From the previous review it would appear that none of the available systems can be applied to classify composites by these individuals because the criterion for the several classes within the systems are vague and/or lack specificity, or contain descriptives about a manufacturing process that is often proprietary. If one cannot apply the classification to a composite to verify that the material fits the criterion or descriptives for that class, then a major problem exists. In such cases one must then rely on the manufacturers information sheet or data presented in a research publication that may or may not be accurate. For example, Visio-Fil® has been described as both a fine particle composite (filler particle size approximately 0·5 μm, Leinfelder, 1989) and as an 'intermediate' type composite (filler particles size from 1–5 μm, Leinfelder, 1989). Visio-Fil® has also been described as a macrofilled composite resin (filler particle size between 0·1–100 μm, Crumpler *et al.*, 1988). In another publication, is Visio-Fil® a composite resin containing macrofiller particles, or is it one that contains fine particles, or is it a blend? Applying any one of the systems to a Visio-Fil® sample to determine its class is rather difficult.

In materials science, microstructure is one of the keys to understanding material properties. Thus, understanding wear resistance for example, requires one to study the role of the filler particle, one of the components in a composite resin. In the past, investigators have relied, in part, on these classification systems to describe the filler particle contents of the composite for the purpose of developing correlations between wear and filler particle size. It is not unusual to see reports that wear resistance is improved in composites that contain smaller filler particles because the wear of a composite classified as a microfilled composite demonstrated better wear resistance values than one classified as a traditional composite. The assumptions are 2-fold: 1) that microfilled composites have smaller particles than traditional composites, and 2) the classification of the composites in question is accurate. Neither assumption may be correct.

To demonstrate the problems that exist, 12 composite resins were selected for study, based on their published classification types, to examine the null hypothesis that: 'There are no differences in the filler particle sizes between composites grouped according to their classification category as traditional, fine particle, or blends using the several classification systems'.

Methods and materials

The 12 composite resins selected for this investigation based on their published composite classifications types (Leinfelder, 1989; Farah & Powers, 1984; Farah & Powers, 1986) were: two microfilled composite resins (Heliomolar®, and Distalite®), seven fine particle composites (P–10®, Bisfil I®, Estilux Posterior®, P-30®, Visio-Fil®, Ful-Fil®, and Status®), and three composites classified as blends (Herculite-Condensable®, Sinter-Fil II®, and Adaptic II®).

A 0·5 g sample of each composite was placed in 5·0 ml of the solvent Acetone and centrifuged for 2 min at 1000 rpm to separate the solvent and matrix substance from the filler particles. This process was repeated three times using the Acetone. The remaining composite mass was next placed in 5·0 ml of Chloroform for further washing and separation of the filler particles which were clumped together as a result of the dissolution in Acetone. The composite mass was again centrifuged for 2 min at 1000 rpm, and the Chloroform and residual matrix substance was discarded. This second washing process was repeated three times. Finally, the remaing filler particles were suspended in 5·0 ml of absolute Ethanol, and the suspended solution and filler particles were smeared on a glass slide.

The glass slides for each composite were initially examined using the scanning electron microscope (SEM) to determine the range of filler particle sizes in each composite. The SEM evaluations were conducted at magnification of 2000 × and 500 × to determine qualitatively the presence of filler particles in the submicron size range as well as particles of much larger dimensions. After establishing the range of filler particle sizes in each composite using the SEM, the samples were photographed at a magnification of 125 × under light microscopic examination and photo enlargements to 500 × were prepared to visually demonstrate the range of sizes present in each composite.

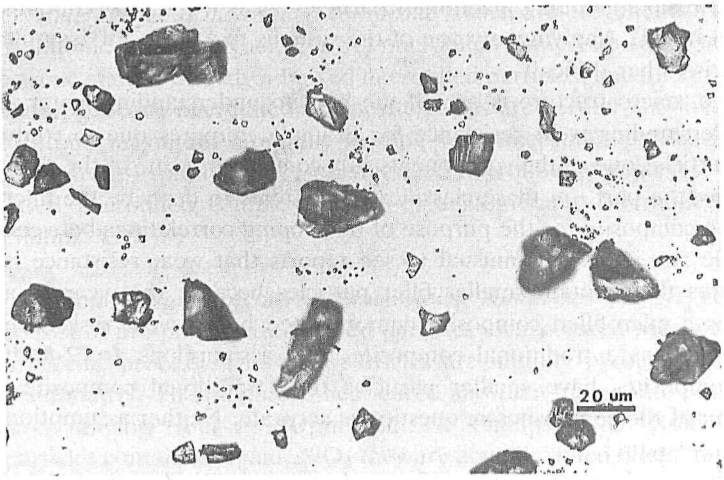

Fig. 1. The filler particles from the composite resin Visio-Fil®.

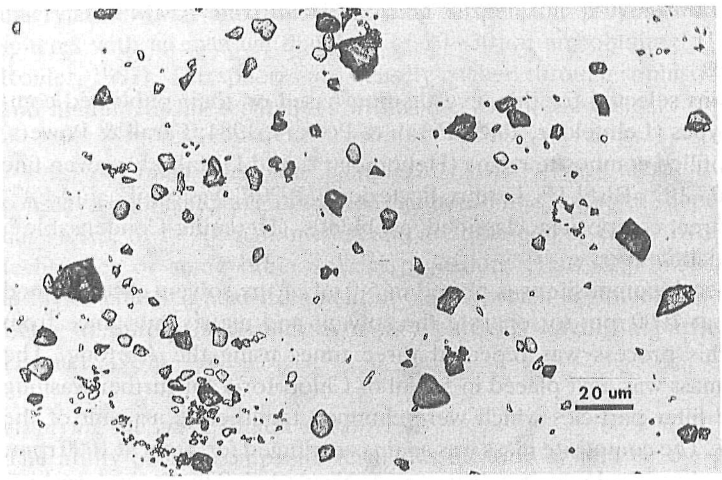

Fig. 2. The filler particles from the composite resin Heliomolar®.

Results

The range of filler particle sizes in each of the 12 composites (Figs 1–12) are presented as photo enlargements to 500 × from light microscopic photographs at 125 × magnification. Based on the filler particles sizes observed during the SEM evaluation, the 12 composite resins would appear to fall into four groups. The first group containing filler particles that range in sizes from submicron to greater that 25 µm are: Visio-Fil®, Heliomolar®, Status®, and Distalite®. The second group with filler particles that range in sizes from submicron to approximately 10 µm are: P–10®, P–30®, Bisfil I®, and Estilux Posterior®. The third group of composite with filler particles in the submicron to 5 µm range are: Adaptic II®, Ful-Fil®, and Sinter-Fil II®. The composite Herculite-

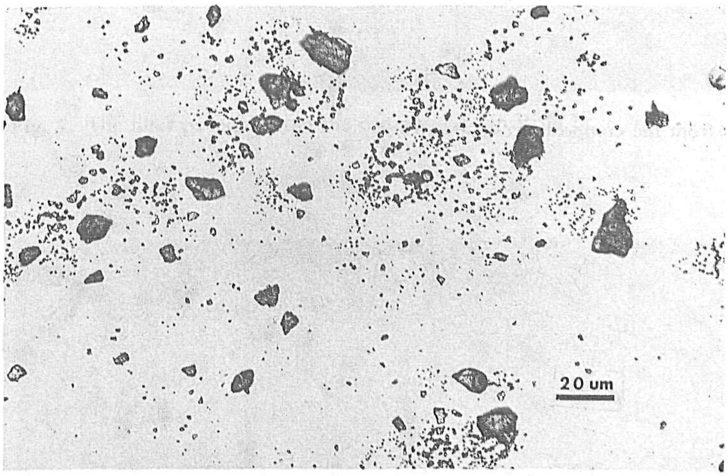

Fig. 3. The filler particles from the composite resin Status®.

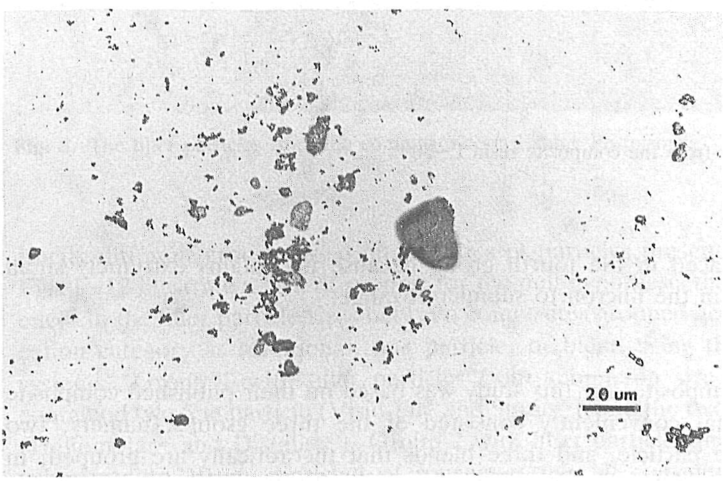

Fig. 4. The filler particles from the composite resin Distalite®.

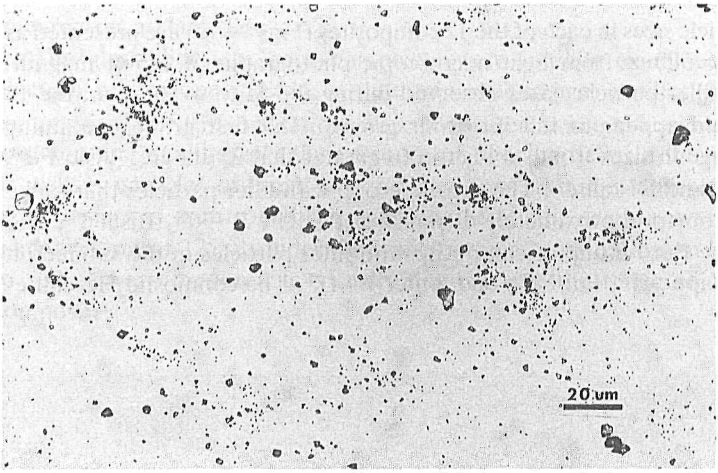

Fig. 5. The filler particles from the composite resin P−10®.

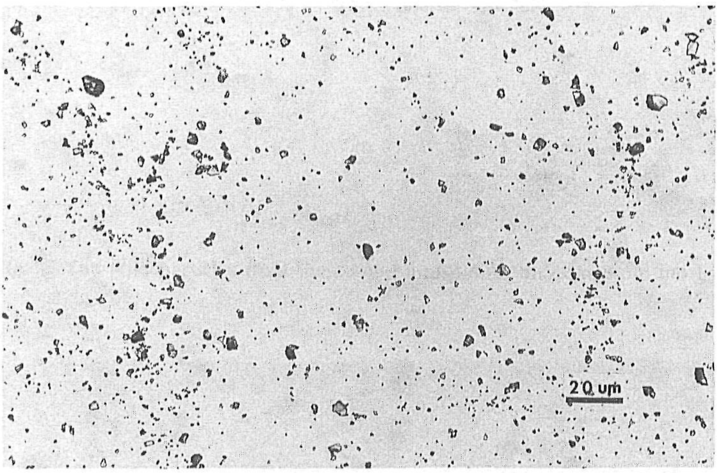

Fig. 6. The filler particles from the composite resin P−30®.

Condensable® was placed in the fourth group because it contains extremely small filler particles mostly in the micron to submicron range.

Discussion

Selection of the 12 composites for this study was based on their published composite classification types that conveniently consisted of the three groups; namely, two microfilled, seven fine particle, and three blends that theoretically are grouped, in part, on the size of their filler particle content. However, the light microscopic examination of the washed filler particles for these same 12 composites produced four dis-

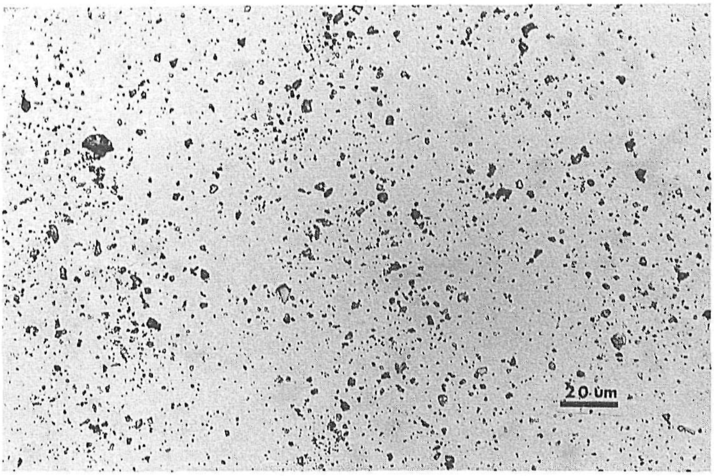

Fig. 7. The filler particles from the composite resin Bisfil I®.

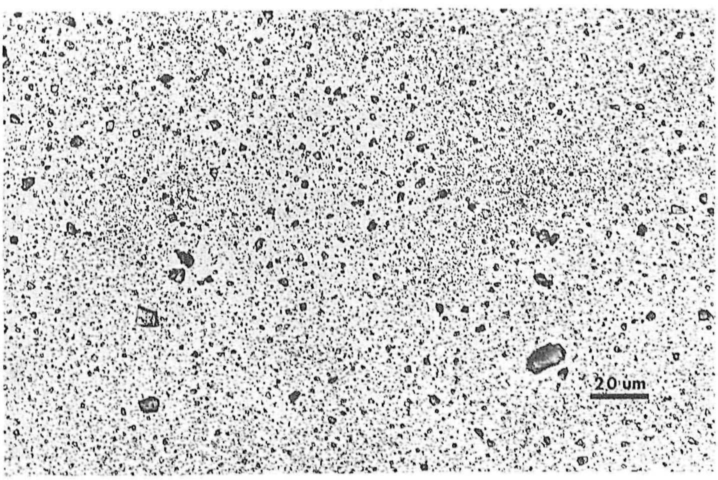

Fig. 8. The filler particles from the composite resin Estilux Posterior®.

tinctly different groups based on the sizes of particles present. The filler particles in Figs 1–12 illustrate a lack of support for the null hypothesis that: 'There are no differences in the filler particle sizes between composites grouped according to their classification category as traditional, fine particle, or blend using the several classification systems'. Group 1 with filler particles from submicron size to greater that 25 μm contained two fine particle (Visio-Fil® and Status®), and the two microfilled composites (Heliomolar® and Distalite®). Group 2 with filler particles that ranged in sizes from submicron to 10 μm consisted of four materials all considered to be fine particle (P–10®, P–30®, Bisfil I®, and Estilux Posterior®). Group 3 with filler particles from

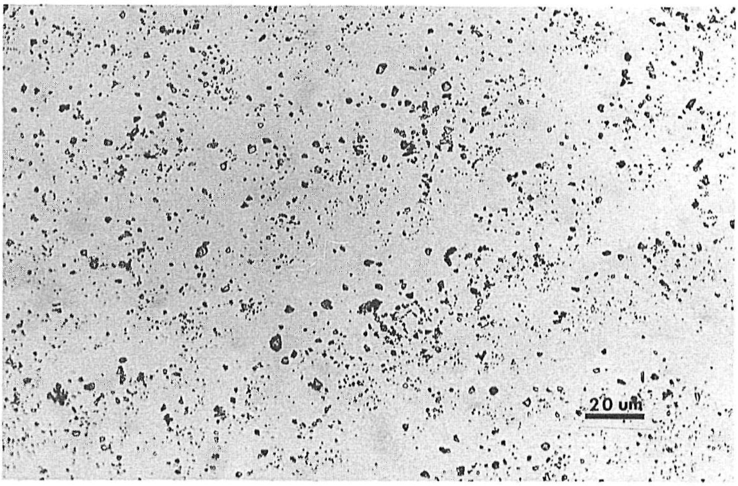

Fig. 9. The filler particles from the composite resin Adaptic II®.

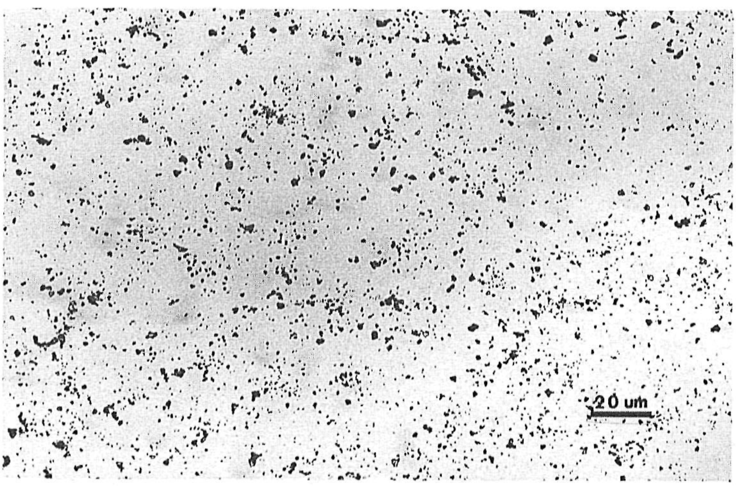

Fig. 10. The filler particles from the composite resin Ful-Fil®.

the submicron range to 5 μm contained one fine particle (Ful-Fil®) and the two blends (Sinter-Fil II® and Adaptic II®). The final material in group 4 was a blend (Herculite-Condensable®) that contained filler particles mostly in the micron to submicron range.

In an earlier study (Lang, *et al.*, 1992) the 12 composites had been examined for wear resistance and the wear volume loss in mm^3/mm^2 for the various materials is presented in Fig. 13. The mean wear volume loss for each materials was compared to the alloy control and the other composites using the Independent Student's *t*-test and the *P* values are presented in Fig. 14. It is interesting to compare the wear data for the composites by separating them into their classification types and their groupings

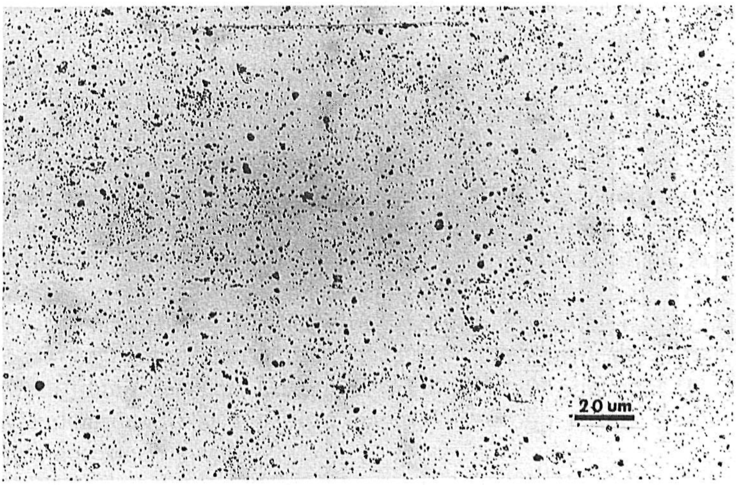

Fig. 11. The filler particles from the composite resin Sinter-Fil II®.

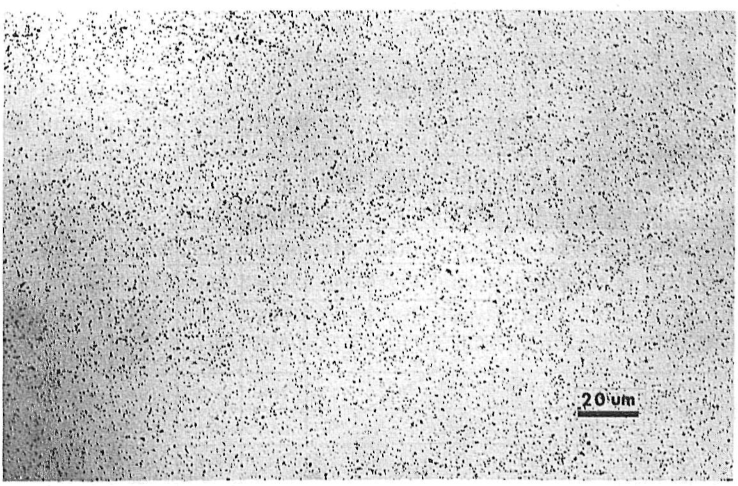

Fig. 12. The filler particles from the composite resin Herculite-Condensable®.

produced by the washed filler particle method. Using this approach one can examine the composite wear for statistically significant differences between materials within a group. Differences between groups can be determined by calculating the mean wear for each group and then computing the differences using the Student's *t*-test. In Fig. 14, using the conventional classification types for grouping, there was no statistically significant differences between the two microfilled composites Heliomolar® and Distalite®. On the other hand, for the fine particle composites there was a statistically significant difference between P−10® and Bisfil I®, P−30®, and Ful-Fil.109. There was also a statistically significant difference in wear between Bisfil I® and

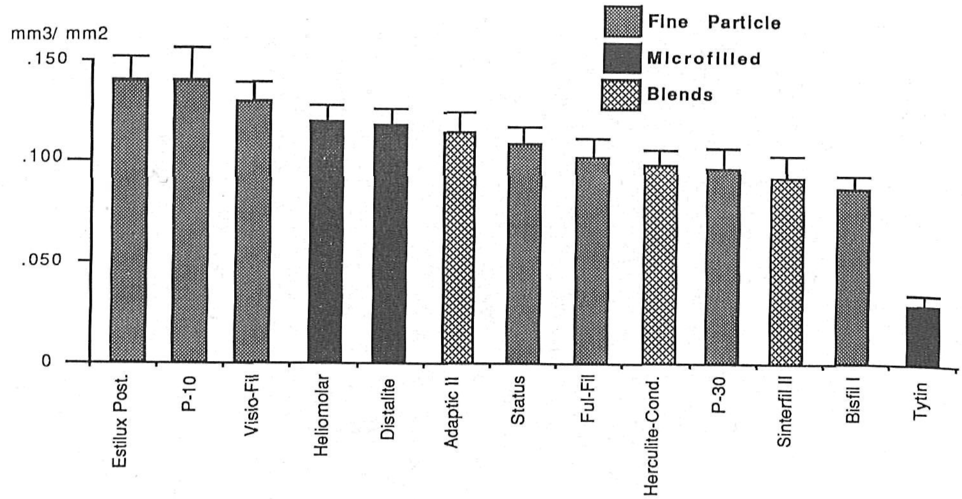

Fig. 13. Composite resin and amalgam mean wear volume loss.

	P-10	Visio-fil	Heliomolar	Distalite	Adaptic II	Status	Ful-Fil	Herculite Cond.	P-30	Sinterfil II	Bisfil I	Tytin
Estilux Post.	.995	.514	.172	.136	.108	.034*	.013*	.005*	.009*	.006*	.000*	.000*
P-10		.595	.276	.239	.185	.092	.043*	.027*	.033*	.021*	.004*	.000*
Visio-fil			.429	.342	.265	.095	.034*	.013*	.023*	.013*	.001*	.000*
Heliomolar				.863	.656	.339	.133	.058	.085	.048	.003*	.000*
Distalite					.768	.430	.177	.080	.114	.066	.004*	.000*
Adaptic II						.708	.363	.235	.253	.155	.033*	.000*
Status							.513	.320	.344	.204	.031*	.000*
Ful-Fil								.807	.756	.502	.194	.000*
Herculite-Cond.									.914	.611	.227	.000*
P-30										.716	.384	.000*
Sinterfil II											.713	.000*
Bisfil I												.000*

Fig. 14. *P*-values from Independent Student's *t*-test comparing the wear volume loss of composite resins and an amalgam control. * Statistically different of the 5% level of significance.

Estilux Posterior®, Visio-Fil® and Status®. Estilux Posterior® also had wear values that were statistically difference than P–30®, Ful-Fil® and Status®. The composite P–30® also demonstrated a statistically significant difference for wear when compared to Visio-Fil®. The wear volume loss for Visio-Fil® was also statistically different than Ful-Fil®. It was very apparent that major differences existed between composites listed in this group by the currently available classifications systems. The group listed as blends consisting of Herculite-Condensable®, Sinter-Fil II®, and Adaptic II® demonstrated no statistically significant differences in their wear.

Examination of the data using the washed particles groupings demonstrated that within group 1, the composites Visio-Fil®, Heliomolar®, Status® and Distalite® demonstrated no statistically significant differences for wear (Fig. 14) In group 2, the composite differences did exist between the several composites. The wear for P−10® was statistically significantly different when compared to both P−30® and Bisfil I®, while no difference was found when compared to Estilux Posterior®. There was no differences between P−30® and Bisfil I®, however a difference was found that was significant between Estilux Posterior®. There was a statistically significant difference between Bisfil I® and Estilux Posterior®. No statistically significant difference in wear were found between Adaptic II®, Ful-Fil® and Sinter-Fil II® in Group 3. Herculite-Condensable® was the only material in group 4 and therefore comparisions were not necessary.

It has been reported that filler particles are not the only factor in the microstructure of composites that influence wear and therefore these differences between the composites within a group in either the classification types or the washed particle groupings is not unexpected. On the other hand if filler particles are significant contributors to wear as has been reported, then comparisons between the groups as organized by filler particle sizes (microfilled versus fine particle and blends) in the classification types and sizes grouped from a qualitative perspective using the light microscope (0·1−25, 0·1−10, 0·1−5, and 0·1−1·0 μm) should demonstrate some differences. In Fig. 15, between group comparison for the classification system types demonstrates a statistically significant difference only between the microfilled composites and the blends ($P = 0{\cdot}041$). Statistically significant differences are not apparent between the other groups. The absence of statistically significant differences between the microfilled and fine particle groups is most probably due to the many within groups differences in the fine particle composites. More important perhaps is the failure of the classification system criterion to separate the composites into more appropriate classes or simply that the published information about the classification type for each composite is in error.

	Fine Particle	Blends
Microfilled	0.640	0.041*
Fine Particle		0.079

Fig. 15. *P*-values from Independent Student's *t*-test comparing the wear volume loss of composite resins grouped using the classification system. * Statistically different at the 5% level of significance.

Fig 16 showing group comparions for the four washed particle groupings demonstrates statistically significant differences between group 1 (0·1–25 μm) and group 3 (0·1–5 μm) ($P = 0{\cdot}019$) and group 4 (0·1–1·0 μm) ($P = 0{\cdot}027$). Differences between groups 2 and group 3 or 4 are not apparent which could be attributed to the smaller differences in the sizes of the filler particles in these groups or obviously the influence of other composite components in the wear process. In any case, grouping the composites on the basis of their qualitative composition of the filler particles appears to more clearly demonstrate the influence of the filler particle on wear.

In the published information on filler particle sizes and the classes within a system, the fine particle composites were to contain 0·5–1·0 μm filler particles (Leinfelder, 1989; 1991). The microfilled composites were to contain filler particles ranging in size from 0·05–0·1 μm with the newer materials having polymerized particles of approximately 20–25 μm (Leinfelder, 1989; 1991). Examination of both Heliomolar® and Distalite® using the washed filler particles in Figs 1 and 2 certainly does not illustrate composites with filler particle sizes of 0·05–1·0 μm. They do however, demonstrate filler particles in the range of 20–25 μm. The fine particle composites should have filler particles that approximate 0·5–1·0 μm in size. Of the seven fine particle composites studied clearly Status® (Fig. 3) and Visio-Fil® (Fig. 1) do not fit the criterion. In fact, most of the fine particle composites have particles much larger than the 0·5–1·0 μm. The blends on the other hand contain filler particles ranging in size from just a few hundred nanometers in diameter (Soderholm, 1985), to particles with an average size of 0·8–1·0 μm (Roulet, 1987). In the composites selected for this project, Herculite-Condensable® (Fig. 12) fits the description, while Adaptic II® (Fig. 9) and Sinter-Fil II® (Fig. 11) have filler particles that are much larger.

Mean wear values were calculated for the several composites in the microfiller, fine particle and blend classes. The mean wear values for these classes are presented in Fig. 17. Moving from left to right the wear decreases directly with a decrease in filler particle size even though one might quesiton if the filler particle sizes in the microfilled composites are larger than those in the fine particle composites. Certainly, Heliomolar® (Fig. 2) and Distalite® (Fig. 4) have large particles; however, one might

	Group 2 (0.1 - 10 μm)	Group 3 (0.1 - 5 μm)	Group 4 (0.01 - 1.0 μm)
Group 1 (0.1- 25 μm)	0.686	0.019*	0.027*
2 (0.1- 10 μm)		0.131	0.195
3 (0.1- 5 μm)			0.718

Fig. 16. *P*-values from Independent Student's *t*-test comparing the wear volume loss of composite resins grouped according to filler particle size as determined by the washing technique. * Statistically different at the 5% level of significance.

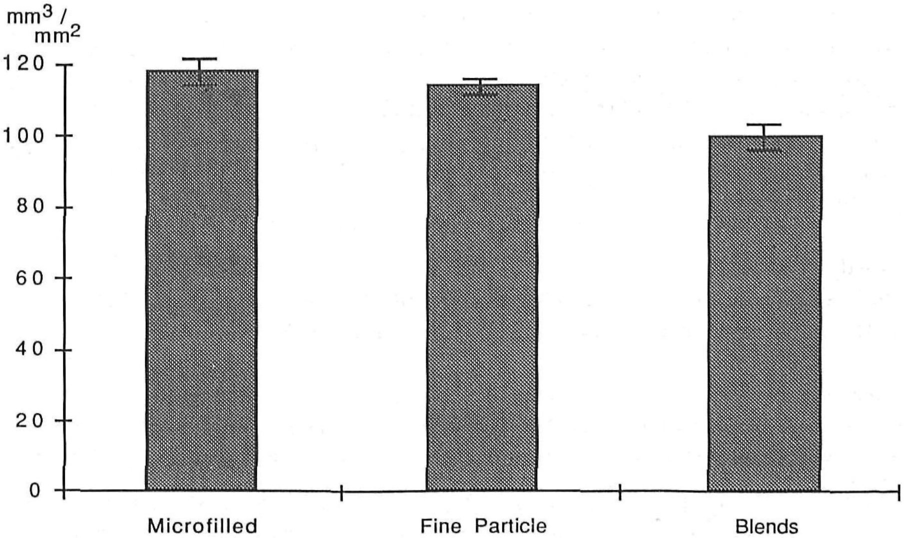

Fig.17. Mean wear volume loss for the composite resins grouped using the classification system.

question if they should be called microfilled composites. In Fig. 18 the mean wear values are presented for the composites grouped by the washed filler particles method. The correlation between filler particle size and wear is much more apparent in Fig. 18. The larger the filler particles within a composite resin, the greater the wear.

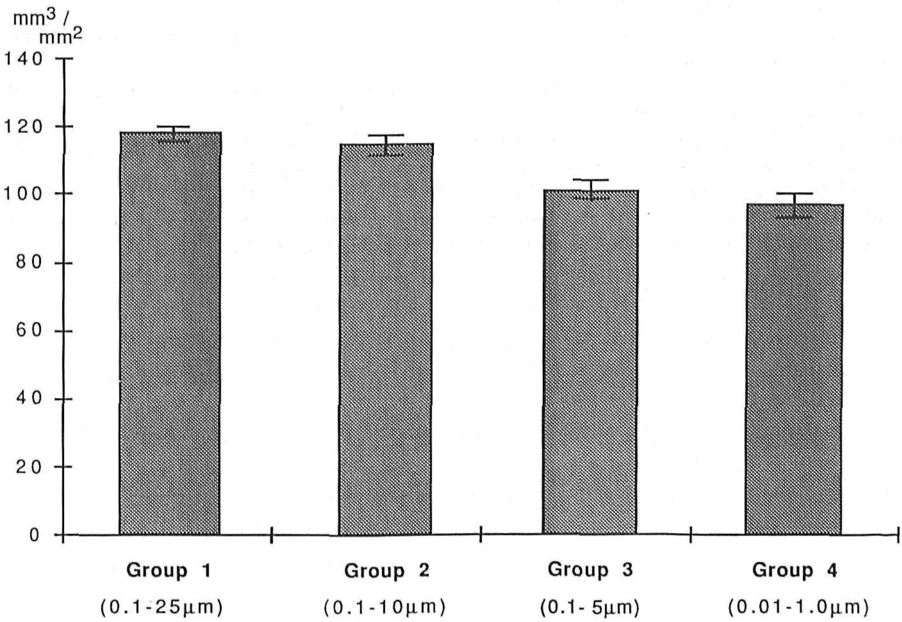

Fig. 18. Mean wear volume loss for the composites grouped using filler particle size as determined by the washing technique.

The results of this study would appear to indicate that classification systems for composite resins should be reviewed. If investigators cannot apply the classification systems to a composite and accurately and reliably verify that the composite is appropriately classified, then the utility of the system should be questioned. Certainly, using the system's classification nomenclature (fine particle, microfilled, etc.,) to report correlation with the physical properties of composites in general must be questioned in the light of this project.

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