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Effect of the type of LED polymerization unit on the compressive strength of conventional and bulk-fill composite resins: an *in vitro* study

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ABSTRACT

Objective: To determine the effect of the type of LED polymerization unit on the compressive strength of conventional and bulk-fill composite resins. **Materials and methods:** Two conventional composite resins (3M Filtek® Z350 XT and Palfique® LX5), two bulk-fill composite resins (Tetric N-Ceram® Bulk Fill and 3M Filtek® One Bulk Fill), and two LED polymerization units (3M Elipar® DeepCure-L, single-wave emission, and Bluephase® N G4, polywave emission) were used. Eight experimental groups were formed, each consisting of ten specimens (n = 80). Bulk-fill resin samples were fabricated in cylindrical molds measuring 4×5 mm by applying a single 4-mm increment of material. A celluloid strip and a microscopy coverslip were used during light curing for 20 seconds. Conventional resin samples were prepared in two increments of 2 mm each. The first increment was placed in a cylindrical mold measuring 2×5 mm, following the described procedure; the specimen was then transferred to a 4×5 mm mold where the second increment was applied, repeating the same procedure. The samples were coded and stored in distilled water in an incubator (24 h, 37 °C); subsequently, they were subjected to compressive strength testing (0.5 mm/min) using a universal testing machine. Data were analyzed using the Kruskal-Wallis statistical test. **Results:** No statistically significant differences in compressive strength were found among the resins light-cured with the 3M Elipar® DeepCure-L unit ($p < 0.105$) or with the Bluephase® N G4 unit ($p < 0.109$). **Conclusion:** The type of LED polymerization unit did not significantly affect the compressive strength of the composite resins evaluated under the experimental conditions of this study.

Keywords: composite resin; polymerization; compressive strength; bulk fill resins.

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INTRODUCTION

LED (Light Emitting Diode) polymerization units are devices used to activate the photoinitiators present in composite resins and trigger the polymerization process, which consists of the transformation of monomers into polymers (1–3). Therefore, the polymerization of these resins constitutes a factor involved in the quality and durability of dental restorations. In this context, the choice of the type of polymerization unit may influence the physical properties of the material, including compressive strength (4,5), defined as the ability of a material to withstand compressive forces before undergoing permanent deformation or fracture (6). For this reason, this property is essential to ensure the integrity and longevity of restorations, especially in the posterior region, since it is constantly subjected to significant occlusal forces (7). In this regard, the compressive strength of composite resins depends on several factors, such as particle size, restorative layer thickness, degree of polymerization, density, polymerization shrinkage, and water sorption (8).

Nowadays, two types of LED polymerization units are used: monowave and polywave. Monowave units were designed to activate the photoinitiators of most resin-based materials and are characterized by emitting blue light (9,10). In contrast, polywave units emerged to meet the need for activating composite resins containing alternative photoinitiators that require not only blue light but also violet light spectra (11,12).

Composite resins are restorative materials used to replace the loss of dental tissues caused by caries, trauma, erosive lesions, among other conditions (13,14). Their variants include conventional composite resins and bulk-fill composite resins, among others (14,15). Conventional resins are placed in increments of up to 2 mm (incremental technique), whereas bulk-fill resins allow applications of up to 4–5 mm, which simplifies the restorative process (16,17).

To achieve greater depth of polymerization, modifications were made to the composition of conventional resins, specifically in the photoinitiators, organic matrix, and inorganic filler material (18). The most common photoinitiator, camphorquinone, has a maximum absorption peak at 468 nm, within an effective range of 360–510 nm; its activation requires a co-initiating amine to generate free radicals through an electron transfer mechanism (19,20).

In contrast, bulk-fill resins employ more advanced photoinitiator systems, such as Ivocerin and Lucirin, which allow greater efficiency even in thicker increments. Ivocerin has an absorption peak at 418 nm (370–460 nm) and is characterized by generating two free radicals per molecule without requiring co-initiators (21,22). Lucirin, in turn, acts through a cleavage mechanism with a maximum absorption peak at 400 nm (380–425 nm), providing high reactivity in shorter exposure times. The correct selection of the photoinitiator system and its compatibility with the wavelength ensures adequate monomer-to-polymer conversion, in addition to improving the physical, mechanical, and esthetic properties of the restorative material (23,24).

The organic matrix also plays a fundamental role in compressive strength. It consists of monomers (tiny low-molecular-weight particles), among which bisphenol A-glycidyl methacrylate (Bis-GMA) and ethoxylated bisphenol A dimethacrylate (Bis-EMA) are the most commonly used in conventional resins (25,26). Conversely, urethane dimethacrylate (UDMA), triethylene glycol dimethacrylate (TEGDMA), dodecanediol dimethacrylate (DDDMA), and addition-fragmentation monomers (AFM) predominate in bulk-fill resins. These latter monomers are distinguished by their greater transparency, sensitivity to light sources, and rapid polymerization process (27).

Regarding the inorganic filler material, both types of resins share components such as zirconia, silica, and clustered filler aggregates. Therefore, the interaction between the type of LED polymerization unit and the type of composite resin (conventional or bulk-fill) may produce differentiated effects on compressive strength (28). However, there is still a gap in understanding how LED units (monowave or polywave) specifically influence this property.

Consequently, this study aimed to evaluate the effect of the type of LED polymerization unit on the compressive strength of conventional and bulk-fill composite resins. The null hypothesis states that the type of LED polymerization unit does not affect this property in either of the two evaluated types of composite resins.

MATERIALS AND METHODS

An *in vitro* preclinical experimental study with a cross-sectional, prospective, and quantitative design was conducted. Two conventional composite resins were used: 3M Filtek® Z350 XT (Solventum; Minnesota, USA) and Palfique® LX5 (Tokuyama Dental; Tokyo, Japan); as well as two bulk-fill composite resins: Tetric N-Ceram® Bulk Fill (Ivoclar Vivadent; Schaan, Liechtenstein) and 3M Filtek® One Bulk Fill (Solventum; Minnesota, USA) (Table 1).

Table 1. Conventional and bulk-fill composite resins evaluated in the study.

Composite Resin (shade)	Manufacturer (batch)	Photoinitiator	Classification (particle size)	Organic matrix*	Inorganic filler weight percentage*
3M Filtek® Z350 XT (A2)	Solventum, Minnesota, USA (9712769)	CQ	Nanofilled (0.01–3.5 µm)	Bis-EMA, Bis-GMA, UDMA, TEGDMA	Mixed oxides, silica oxides, nanoclusters (82 wt%; 78.5 vol%)
Palfique® LX5 (A2)	Tokuyama Dental, Tokyo, Japan (268E13)	CQ/RAP	Supra-nano (0.01–3 µm)	Bis-GMA, TEGDMA	Silica-zirconia oxides (82 wt%; 71 vol%)
Tetric N-Ceram® Bulk Fill (IV A)	Ivoclar Vivadent, Schaan, Liechtenstein (Z05DXN)	Ivocerín	Nanohybrid (0.04–3 µm)	Bis-GMA, Bis-EMA, UDMA	Methacrylates, barium glass, trifluoride, mixed oxides, pigments 1% (80 wt%; 61 vol%)
3M Filtek® One Bulk Fill (A2)	Solventum, Minnesota, USA (10124596)	Not specified	Nanofilled (0.01–3.5 µm)	AFM, AUDMA, UDMA, DDDMA	Mixed oxides, silica oxides, zirconium oxide, nanoclusters (76.5 wt%; 58.5 vol%)

CQ: camphorquinone; RAP: radical amplified photopolymerization; Bis-EMA: ethoxylated bisphenol A dimethacrylate; Bis-GMA: bisphenol A-glycidyl methacrylate; UDMA: urethane dimethacrylate; AUDMA: aromatic urethane dimethacrylate; TEGDMA: triethylene glycol dimethacrylate; AFM: addition-fragmentation monomers; DDDMA: dodecanediol dimethacrylate.
* Data provided by the manufacturer.

Two LED polymerization units were used: 3M Elipar® Deep Cure-L (Solventum; Minnesota, USA), a monowave unit with an irradiance of 1470 mW/cm² and a wavelength range of 430–480 nm; and Bluephase ® N G4 (Ivoclar Vivadent; Schaan, Liechtenstein), a polywave unit with an irradiance of 950–1500 mW/cm² and a wavelength range of 385–515 nm.

Compressive strength was considered a quantitative variable, whereas the type of LED photopolymerization unit (monowave and polywave) and the type of composite resin (conventional and bulk-fill) were included as qualitative variables.

Given the characteristics of this *in vitro* study, an evaluation by an Ethics Committee was not required. Nevertheless, the protocol was reviewed and approved by the Research Area of the Stomatology Program of the Faculty of Health Sciences at Universidad Científica del Sur. The process was conducted in accordance with the provisions of Board Resolution No. 12-DGIDI-CIENTIFICA-2021, regarding the rules and guidelines for exemption from the Ethics Committee, and was registered in 2023 under code No. POS-53-2023-00368.

Study groups

The population consisted of the conventional and bulk-fill composite resin specimens previously described, fabricated according to the experimental study parameters detailed below. A non-probability sampling method was used.

The following inclusion criteria were established: resins from the proposed brands, processed according to the manufacturing parameters of the aforementioned LED polymerization units, and free of any visible structural alterations. As exclusion criteria, specimens presenting scratches, bubble formation, or inadequate condensation were discarded.

For sample size calculation, a pilot study was conducted with eight experimental groups comprising three specimens each (n = 24), distributed as follows: G1 (control), 3M Filtek® Z350 XT/3M Elipar® DeepCure-L; G2, 3M Filtek® Z350 XT/Bluephase® N G4; G3, Palfique® LX5/3M Elipar® DeepCure-L; G4, Palfique® LX5/Bluephase® N G4; G5, 3M Filtek® One Bulk Fill/3M Elipar® DeepCure-L; G6, 3M Filtek® One Bulk Fill/Bluephase® N G4; G7, Tetric N-Ceram® Bulk Fill/3M Elipar® DeepCure-L; y G8, Tetric N-Ceram® Bulk Fill/Bluephase® N G4.

Once the results were obtained, the mean and standard deviation values of each group were used to determine the final sample size using G*Power software (version 3.1.9.7), applying the hypothesis-testing method. Although the statistical analysis established an initial total of 56 specimens (n = 7 per group), three additional units per group were included to compensate for potential losses during the experiment. Consequently, the final sample consisted of eighty specimens (n = 80), with ten units per group (n = 10), maintaining the same distribution of materials and polymerization units used in the pilot phase.

Specimen preparation

For the preparation of specimens, the guidelines established in ISO 4049:2019 were followed, which specify the requirements for physical properties and standardized testing methods for dental biomaterials (6).

For the bulk-fill resins, a cylindrical mold measuring 4×5 mm was positioned on a glass slab. Using a composite resin spatula, 4 mm of material was inserted, over which a celluloid strip and a microscopy coverslip were placed. After applying gentle digital pressure, photopolymerization was performed through these layers for 20 seconds using the LED polymerization unit assigned to each experimental group.

Conventional composite resin specimens were prepared using the incremental technique in two 2-mm layers. The first increment was placed in a 2×5 mm cylindrical mold following the procedure described above; subsequently, the specimen was transferred to a 4×5 mm mold, where the process was repeated for the second layer. All specimens were coded, immersed in distilled water, and stored in an incubator at 37 °C for 24 h.

Compression test

After the specified 24-hour period, all specimens underwent compressive strength testing using a universal testing machine (CMT-5L, Jinan Liangong Testing Technology Co., Ltd.; Shandong, China) at a loading speed of 0.5 mm/min. The obtained values were recorded in megapascals (MPa) and organized into tables according to the corresponding experimental group.

Statistical analysis

Once the compressive strength results were obtained, normality and homogeneity of variances were assessed using the Kolmogorov-Smirnov and Levene tests, respectively. Since the data did not exhibit a normal distribution or homogeneity of variances, a nonparametric analysis was performed using the Kruskal-Wallis test for independent samples. Data processing was conducted using the SPSS-25 statistical package (IBM® SPSS Inc.; Chicago, IL, USA), in order to identify whether there were significant differences between the resistance of the resins evaluated and the type of LED polymerization unit used. For all analyses, a 95% confidence level and a significance level of 0.05 were established.

RESULTS

According to the analysis performed using the nonparametric Kruskal-Wallis test, no statistically significant differences in compressive strength were observed among the evaluated groups, both for the composite resins polymerized with 3M Elipar® DeepCure-L ($p < 0.105$) and for those treated with Bluephase® N G4 ($p < 0.109$). On the other hand, the highest comprehensive strength was observed in the conventional resin 3M Filtek® Z350 XT photopolymerized with the Bluephase® N G4 LED unit (polywave), with a median of 315.62 MPa and an interquartile range (IQR) of 57.62. This was followed by the bulk-fill composite resin 3M Filtek® One Bulk Fill photopolymerized with the 3M Elipar® DeepCure-L unit (monowave), with a median of 315.46 MPa and an IQR of 40.50 (Table 2).

Table 2. Compressive strength of the evaluated composite resins according to the type of LED polymerization unit.

Composite resin	3M Elipar® DeepCure-L (monowave)		Bluephase® N G4 (polywave)		p-value
	Median (MPa)	IQR	Median (MPa)	IQR	
3M Filtek® Z350 XT	298.43	72.45	315.62	57.62	0.105*
Palfique® LX 5	274.15	80.23	288.65	39.72	0.109**
3M Filtek® One Bulk Fill	315.46	40.50	293.74	33.04	
Tetric N-Ceram® Bulk Fill	293.29	26.31	291.31	17.57	

IQR: interquartile range.
* $p < 0.05$, Kruskal-Wallis test. Resins photopolymerized with 3M Elipar® Deep Cure L (n = 10).
** $p < 0.05$, Kruskal-Wallis test. Resins photopolymerized with Bluephase® N G4 (n = 10).

Box-and-whisker plots allowed visualization of the distribution and dispersion of the data in each experimental group, confirming the absence of significant differences between the LED polymerization units employed. In these representations, the horizontal line indicates the median values (Figures 1 and 2).

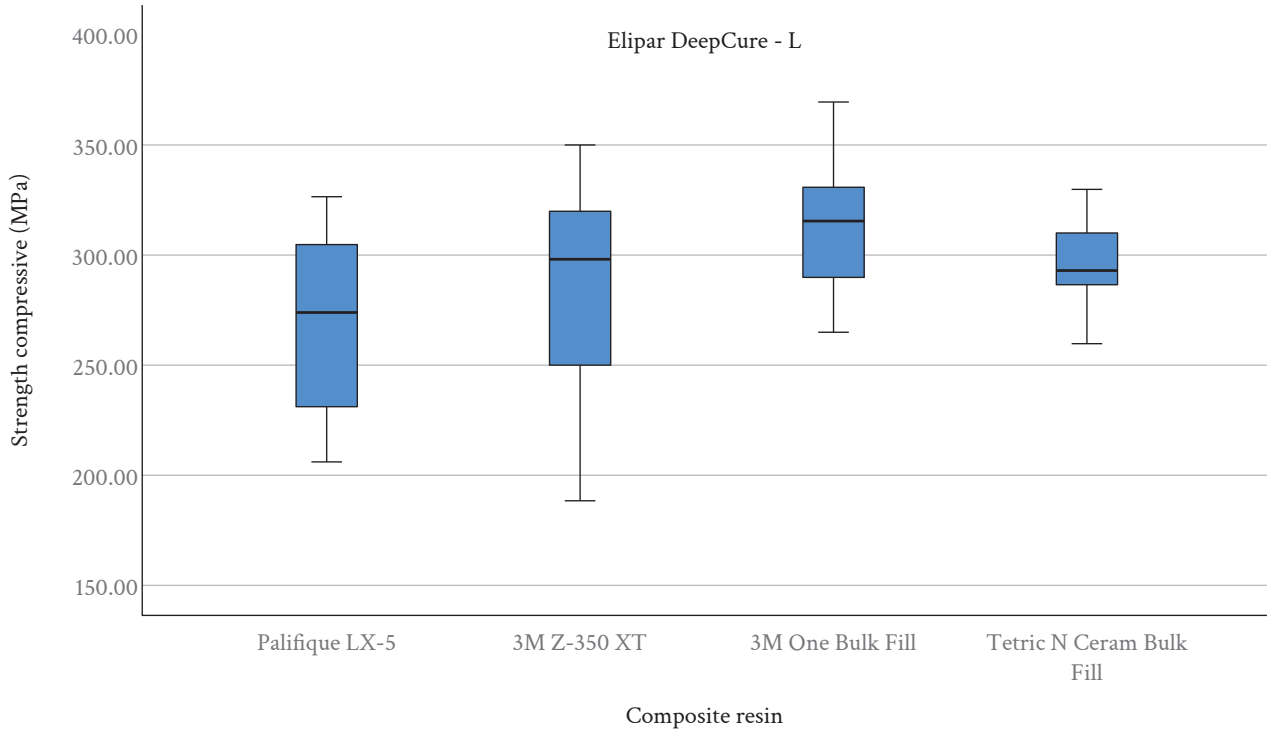

Figure 1. Box-and-whisker plot comparing the compressive strength of the evaluated composite resins polymerized with the 3M Elipar® DeepCure-L LED polymerization unit (n = 10).

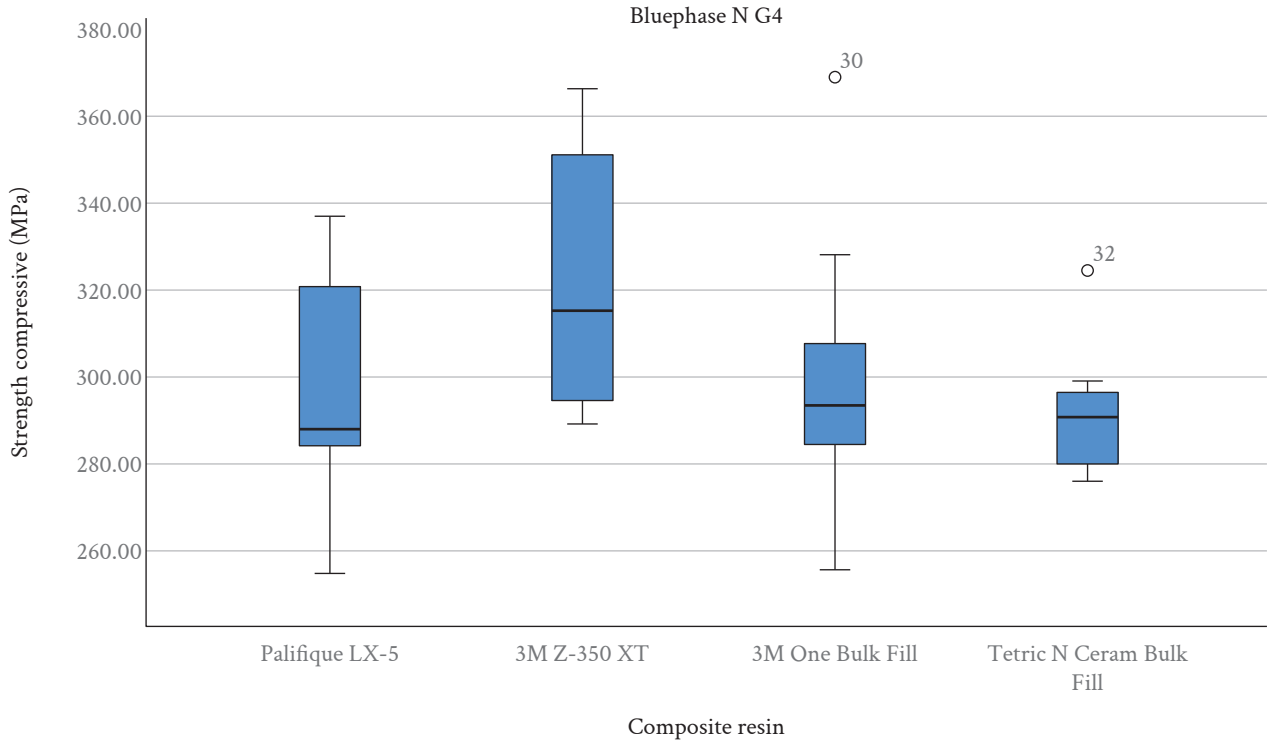

Figure 2. Box-and-whisker plot comparing the compressive strength of the evaluated composite resins polymerized with the Bluephase® N G4 LED polymerization unit (n = 10).

DISCUSSION

The present study evaluated the effect of two LED polymerization units (monowave and polywave) on the compressive strength of two conventional and two bulk-fill composite resins. The findings suggest that both types of materials behaved similarly; therefore, the type of polymerization unit employed did not significantly influence the strength of the evaluated specimens.

Although compressive strength is only one of the mechanical properties of these materials, the results may be influenced by interrelated factors such as the organic matrix, depth of polymerization, photopolymerization time, and wavelength (25,29). In this regard, the organic matrix determines the material's ability to form a dense and resistant polymeric network; consequently, a greater degree of monomer conversion translates into superior mechanical strength (29,30). This conversion, in turn, depends on the depth of polymerization: if the light source does not adequately penetrate deeper layers, the material is not properly polymerized, thereby reducing its strength (30). Similarly, photopolymerization time directly influences this process, since insufficient exposure prevents maximum hardness, whereas excessive exposure may generate internal stresses due to shrinkage (23,31). In addition, the emitted wavelength must match the absorption peak of the photoinitiator in order to activate the reaction efficiently. Control of these variables is fundamental to ensuring adequate compressive strength of composite resins (30,31).

In contrast to the results obtained, Pradeep et al. (32) concluded that the compressive strength of two bulk-fill resins photopolymerized with a monowave LED polymerization unit was greater than the compressive strength of a conventional composite resin. This discrepancy may be due to the fact that the resins used have different formulations with varying inorganic fillers, which confer mechanical stability to the composite resins; therefore, it is likely that the intrinsic characteristics of the resins had a greater impact than the type of polymerization unit (27,33).

Another determining factor is the chemical composition of the organic matrices, specifically regarding the quantity, size, and distribution of particles (26). The evaluated resins possess matrices based on monomers such as Bis-GMA or UDMA, which, due to their highly cross-linkable nature, provide superior mechanical properties. Furthermore, the bulk-fill resins used are high-viscosity materials, which improve structural stability regardless of the type of light used for photopolymerization (28,33).

Similarly, it was observed that the emitted wavelength did not significantly affect the degree of conversion (34). This may be attributed to the compatibility of the photoinitiators (such as camphorquinone and alternative RAP co-initiator systems) with the emission spectrum of both units. Therefore, the combination of adequate light intensity and material composition appears to play a more critical role than the specific emission spectrum (8,34).

Along the same line, Nica et al. (35) compared the physical properties of several composite resins, including compressive strength. Their results indicated that the strength of the evaluated materials—two conventional and one bulk-fill resin—photopolymerized with a monowave LED unit did not exhibit significant variations. This similarity may be attributed to the fact that conventional resins share camphorquinone-based photoinitiator technologies, which are sensitive to the emission range of monowave units (440–480 nm), which favors adequate activation (25,26). Furthermore, some bulk-fill resins incorporate alternative photoinitiators that broaden the sensitivity spectrum, allowing effective polymerization with polywave units (21,27). Regarding irradiance, it remained at adequate average levels (approximately 1000 mW/cm^2), which ensures a sufficient degree of conversion for polymeric network formation with both types of curing lights (22). Consequently, compressive strength values were similar in both groups, regardless of the type of LED unit employed (6).

Although the literature reports divergent results, this study highlights the importance of considering variables beyond the type of LED polymerization unit when determining the compressive strength of restorative materials. One limitation of this study lies in its *in vitro* nature, which prevents complete reproduction of physiological factors present in the oral cavity, such as humidity, temperature fluctuations, salivary pH, and masticatory loading. In addition, since compressive strength is only one of several relevant mechanical properties, excluding analyses of flexural strength, surface hardness, polymerization shrinkage, or degree of monomer conversion limits a comprehensive interpretation of the clinical behavior of the evaluated materials.

In light of these findings, the selection of an LED polymerization unit should be based on the specific requirements of each clinical case, since both monowave and polywave LED polymerization units proved equally effective in terms of compressive strength. Nevertheless, although no differences were found between conventional and bulk-fill resins, it is imperative to consider that final performance may vary according to application and polymerization conditions.

CONCLUSIONS

The type of LED polymerization unit did not affect the compressive strength of either the conventional or the bulk-fill composite resins evaluated. This finding indicates that, under the experimental conditions employed, both types of composite resin exhibited similar performance with respect to this mechanical property. However, it is essential to consider additional factors when selecting an LED polymerization unit, such as the photoinitiator system, the organic matrix (monomers), and the inorganic filler content, among others.

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