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An Undergraduate Research Project to Test a Composite Wetting Resin Material for Dental Applications

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Abstract

This paper describes and presents key results from a multidisciplinary undergraduate research project conducted by a professor at the dental school and an engineering sophomore student at XXXX University. By adopting the educational paradigm of "Learning by Doing", this research project is used as a student learning tool for comprehension and reinforcement of concepts in basic engineering courses in the undergraduate engineering curriculum; such as engineering materials and mechanics of materials. The main purpose of this project is to assess the efficacy of a wetting repair resin called Composite Wetting Resin (Ultradent Product Inc. South Jordan UT), in the adding of uncured composite material to cured composite material. The strength of the composite filling materials was tested using a universal material testing machine. The universal testing machine uses specific strength tests and equations to calculate the overall stress of a composite. Fresh composite samples are made and tested by applying a simple 3-point bend test. In addition, three-dimensional (3-D) numerical models were created and analyzed using the SolidWorks software and its analysis package.The project hypothesizes that the old equations of stress modeling are overestimating the applied stress of dental composite.

Introduction

Low learning retention rate of students is a challenging problem in engineering schools. Over the past years, much research has been done in regards to retention. Research showed that involving engineering students in undergraduate research will have a positive impact on the learning retention of these students of engineering concepts[1-5].When students are exposed to "actual research," they begin to understand that their undergraduate learning experiences are merely building blocks upon which more in-depth learning is based. Exposure to actual research projects in the undergraduate curriculum also serves to enhance the students' curiosity about how their undergraduate course subjects matter and how they can be used to solve more than just "textbook" problems[6].There are different ways for undergraduate students to participate in research activities including on campus research assistant positions, summer research experience programs, independent study research credits, and even research-oriented degree requirements[7].

This paper presents an undergraduate research project that involves a sophomore biomedical engineering student and a faculty member in the School of Dental Medicine at the same university. The engineering department at that university is relatively new and started about 10 years ago and has no graduate programs. One of the educational goals of the project is to improve the students' learning by adopting the concept of "learning by doing". The student became involved in the research project during freshmen year of college, upon completing related engineering courses such as statics, materials and solid mechanics. The student started the project out by making the dental composite samples with actual dental materials and tools, followed by conducting the strength tests. This in turn enabled the student to create a poster presentation at the annual conference of International Association of Dental Research. After completing the hands on experiments, the student started the SolidWorks modeling in the sophomore year.

Background of the Research Point

When a composite resin is cured by free radical induced polymerization in ambient air, the surface layer exposed to air will not polymerize because free radicals are readily absorbed by oxygen. This oxygen inhibited layer is important for the addition of the next layer of added composite, which is then cured and copolymerizes with the oxygen inhibited layer. When no more composite is added to the restoration, the oxygen inhibited layer will either be polished away, or it will erode over time. When an existing composite needs an addition of composite, there is no oxygen inhibited layer to provide adherence, and the composite addition will be less than integral with the existing restoration. Wetting Repair Resins is designed to restore the oxygen inhibited layer prior to the addition of new composite to an existing restoration. This research project compares the flexure strength of composites to that of their repaired samples, with and without the Repair resin applied.

Experimental Procedure

In this research seven different composites are tested. The experiments are conducted in nine steps, starting from making the composite specimen till the break of the repaired composite specimen as shown in Figure 1.

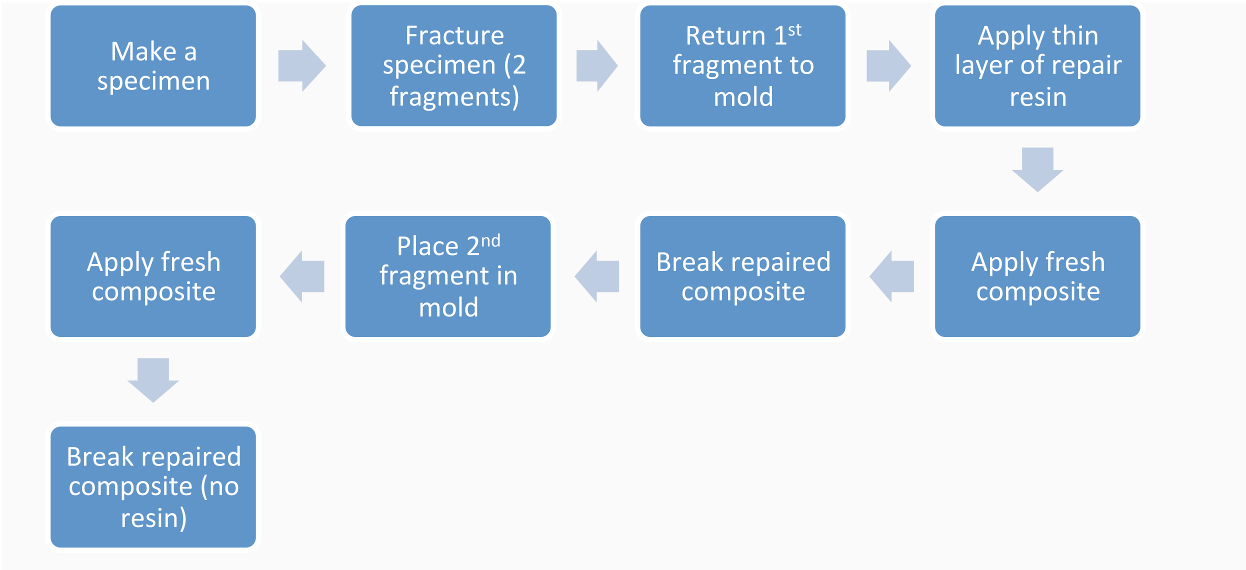

Figure 1. Outline of the experimental procedure.

The flexural strength of the composites is measured using the method described in ISO Standard ISO 4049. ISO 4049 specifies requirements for dental polymer-based restorative materials supplied in a form suitable for mechanical mixing, hand-mixing, or intra-oral and extra-oral external energy activation, and intended for use primarily for the direct or indirect restoration of cavities in the teeth and for luting. The polymer-based luting materials covered by ISO 4049 are intended for use in the cementation or fixation of restorations and appliances such as inlays, onlays, veneers, crowns and bridges[7].

Specimens of size 2x2x25 mm were made in a split mold. Figure 2a shows this mold put on a glass plate to provide a flat composite surface. A dispensing gun was used to place the composite in the mold (Figure 2b). The composite was then manually compacted to fill the mold (Figure 2c) using TiN coated instruments. Excess composite around the edges of the mold was removed (Figure 2d). The specimen was then cured with a conventional THQ curing light for a duration of 25 seconds per increment (Figure 2e). The curing light is used for polymerization of light cure resin based composites.It can be used on several different dental materials that are curable by light. The emitted spectrum of the curing light is 400-500 nm, which is part of the visible light spectrum. A total of six curing cycles were used for each specimen, three per side. Once the composite was cured, it was removed from the mold, labeled, and left untouched for a minimum of 48 hours.

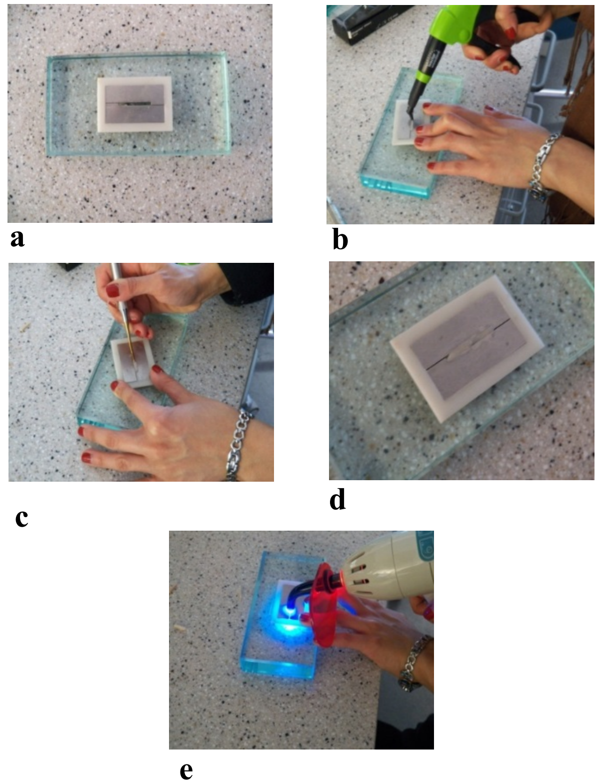

Figure 2. Steps for creating the composite test specimen.

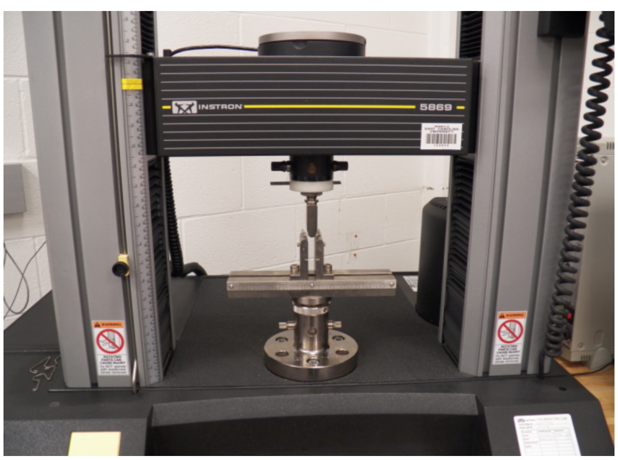

Figure 3. The universal testing machine (Instron 5800 series).

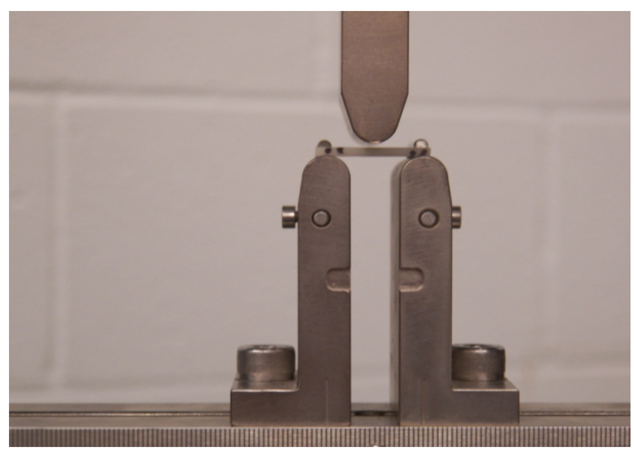

Figure 4. The 3-point bending jig.

Then the sample was placed in the universal testing machine shown in Figure 3 (Instron Model 5567), using a 3-point bending jig with a span of 20 mm and a cross-head speed of 2mm/min (Figure 4). Loads and stresses at fracture points were recorded for each specimen. After fracture, one fragment of the fractured specimen was repaired with the original resin using the Composite Wetting Resin, while the other fragment was repaired without the Wetting Resin. The repair process was similar to the creation process of the specimen. Each specimen was repaired with its respective composite and after storage at ambient conditions, the specimen were re tested through the TFS test. The process was repeated for each different type of composite. Figure 5 shows the broken specimen versus the non-broken specimen.

Figure 5. The broken specimen versus the non-broken specimen.

Experimental Results

Once all the data was obtained, it was analyzed using the Tukey-Kramer HSD method (SAS JMP9). This method is a single-step multiple comparison procedure and statistical test. It is used in conjunction with an ANOVA to find means that are significantly different from each other. It compares the means of specimen treated with the wetting resin to that of the specimen treated without wetting resin; that is, it applies simultaneously to the set of all pairwise comparisons and identifies any difference between two means that is greater than the expected standard error[8].The statistical results are shown in Table 1. New specimens are labeled as (n). The specimens that were repaired with resin are labeled as (rwr). The specimens that were repaired without resin are labeled as (rnr). Figure 6 shows the transverse flexural strength of repaired composites using the ISO 4049 procedure. This technique allows for a more accurate and effective comparable method of whether or not the wetting resin increased the flexural strength of a specimen. Based on the results, the wetting resin did indeed increase the flexural strength of most composite specimen by approximately 20 MPa. However, once a specimen was broken, its final flexural strength decreased by about 50 MPa for those without resin, and about 30 MPa for those with resin, compared to the original flexural strength of the intact specimen. The specimens that were repaired with resin were 80% of the original strength. The specimens that were repaired without resin were 65% of the original strength. On average all resins maintained a strength that met the ISO4049 standard.

Table 1. Statistical analysis of flexural strength by treatment

Means and Std Deviations

Level	Number	Mean	Std Dev	Std Err Mean	Lower 95%	Upper 95%
n	63	134.854	30.6709	3.8642	127.13	142.58
rnr	61	87.330	32.9443	4.2181	78.89	95.77
rwr	49	107.461	45.7009	6.5287	94.33	120.59

Means Comparisons

Comparisons for all pairs using Tukey-Kramer HSD

q*	Alpha
2.36447	0.05

Abs(Dif)-HSD

	n	rwr	rnr
n	-15.282	11.055	32.117
rwr	11.055	-17.328	3.678
rnr	32.117	3.678	-15.531

Positive values show pairs of means that are significantly different.

Level				Mean
n	A			134.85381
rwr		B		107.46143
rnr			C	87.32967

Levels not connected by same letter are significantly different.

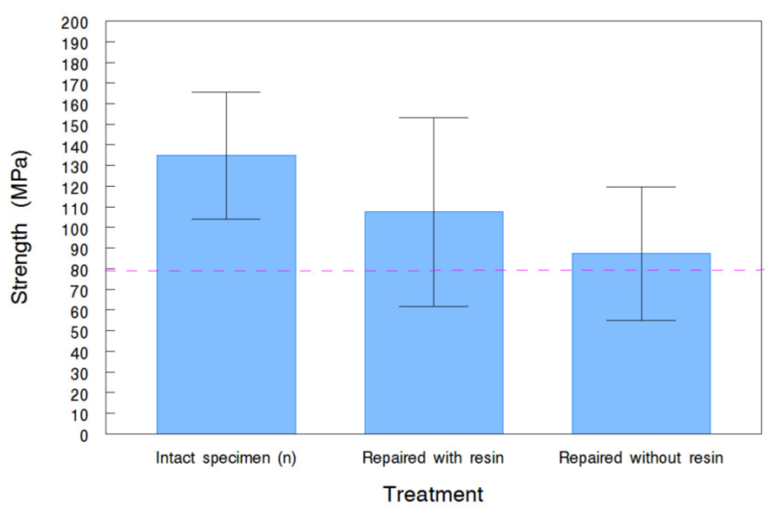

Figure 6. Transverse flexural strength. (Dotted line represents ISO minimum requirement)

Numerical Modeling

As described in the previous sections, the purpose of this project is to improve the flexural strength evaluation of dental restorative composite resins. Mechanical properties of composites are obtained via a universal testing machine, which uses equations derived from simple beam theory to calculate stress levels at fracture. We hypothesize that the equations from the beam theory underestimates the applied stresses to the composites in the testing process because boundary effects are not taken into account. Therefore, 3-D models of the specimens are created in SolidWorks and simulations are carried out using the built in analysis package. The experiments are simulated to obtain stress calculations that includes realistic boundary conditions. In particular we are concerned about the effect of the aspect ratio of the specimens on the final strength determination. If the 3-D modeling on SolidWorks shows that the stress applied to the composite is actually lower than our experimental values (meaning the composite is worse than expected), then the ISO standard for dental composite might need to be altered and reevaluated. However, if the numerical results show that the stress applied is higher (meaning the composite is better than expected), then the Instron data is actually a lower estimate of the applied stress.

SolidWorks Analysis

This phase of the project was started towards the end of the students' sophomore year and was carried out through the beginning of junior year because it required the knowledge of engineering concepts addressed in upperclassman level courses. A 2x2x25 mm beam was created via SolidWorks using a split line method. The beam was constrained in the x, y and z directions on one end and in the x and y on the other, in order to simulate a 3-point Bend test. Different forces of varying loads of 10,20, 30, 40, and 50N were applied to the middle of the beam via SolidWorks simulation. For each load, different elastic modulus values (E) (5,8,10, and 15 psi) and Poisson’s ratio values V (.1,20, 25) were applied. Mesh was generated and max stress values was obtained as seen in Figure 7.

Once all the possible combinations of load, Elastic Modulus, and Poisson's Ratio were completed through simulation, analysis was done to assess the data and to compare it to the data generated by the Instron. The analysis shows that the there was never more than a five percent variation

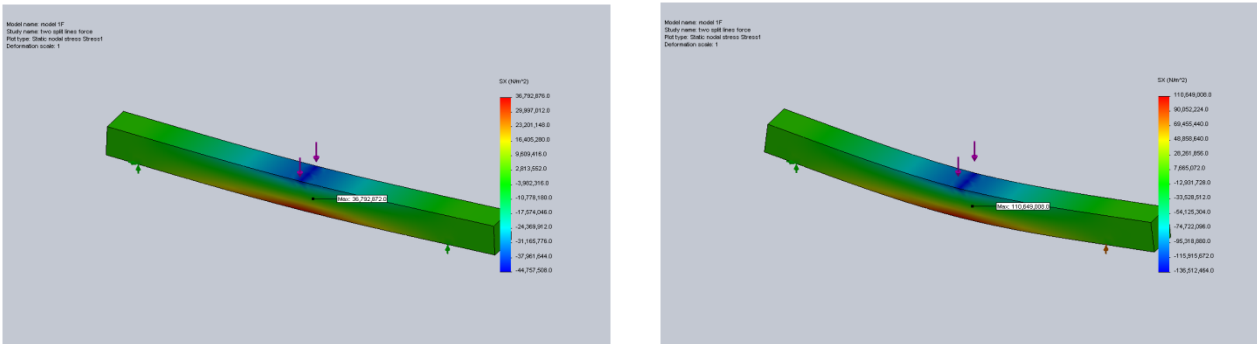

Figure 7: Screenshots of SolidWorks Simulation Model

between the stress values obtained from SolidWorks and the stress values provided by the ISO formula. This means that taking the Elastic Modulus and Poisson's ratio of composites to extremes will not have a significant effect on the overall stress of a material. Therefore, the ISO formula can continue to be used in stress calculations.

Student Learning:

This research project fostered the students' knowledge in many ways. The student got to learn higher level application of Solid Works, through the modeling. The simulations allowed the student to better understand the application of forces on objects as well as the impact of Poisson's Ratio and the Elastic Modulus on materials. Moreover, the experimental aspect of this research allowed the student to gain an insight experience on how to create composite specimen, which is pivotal later on in the field of dentistry.

Conclusion

In summary, this research project helps to foster the engineering students' knowledge of basic engineering concepts such as statics and mechanics of materials. The project started in the student's freshmen year of college and was carried throughout the junior year. The project was broken down into two steps which involved first, making dental composite samples experimentally and testing their flexural strengths through an Instron machine, and second, numerically assessing these results through a SolidWorks simulation model. Both steps led to the conclusion that the ISO formula does not overestimate the applied stress to dental composites, which means that the formula can continue to be used in finite element analysis, whereas the materials Elastic Modulus and Poisson's Ratio have little effect.

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