Designing resin ceramic composites for use in temporary dental implants

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Introduction

The purpose of dental resin implants is to replace lost dental tissue. To function suitably, dental composites should tolerate abrasion and various temperatures without inhibiting mastication. Alshabib et al. (2019) researched the effects of water aging for one day and thirty days and found that exposure to aqueous fluids weakens implants, which affects properties such as wear resistance and hardness. The goal of this project was to develop affordable temporary dental resin composites using biocompatible materials to optimize mechanical properties. Using SLA printing, implants can be personalized and produced efficiently at dental offices. The research hypotheses were that powder additives would affect composite mechanical properties, water aging would affect composite mechanical properties, and there would be an interaction between these independent variables.

Materials and Methods

Specimens were designed in Autodesk Fusion 360 and created using an Elegoo Mars 3 SLA printer. Flexural strength had 10 dry control, aged control, and dry zirconia and 9 aged zirconia samples. For hardness, each group had 5 specimens. For wear resistance, there were 7 dry control, 10 aged control, 4 dry zirconia, and 5 aged zirconia samples. Control specimens only contained D01S dental model resin, and zirconia samples included zirconium oxide (ZrO_2) powder at 25% particle loading. Dry samples were not tested directly after printing. Aged samples were not immediately exposed to moisture after printing; however, they were tested directly after a 14-day aging period. For flexural strength (Figure 1), a three-point bend test was conducted on each specimen until fracture. Sample dimensions were 5.0 × 0.5 × 0.5 cm. A Wilson Hardware Tukon 1202 was used to perform indentation hardness tests (image not shown). For wear resistance, a custom-built wear tester was used to apply a constant force of 0.23 N (Figure 2). Hardness and wear resistance samples were 1 × 1 × 1 cm.

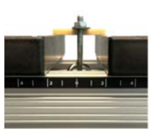
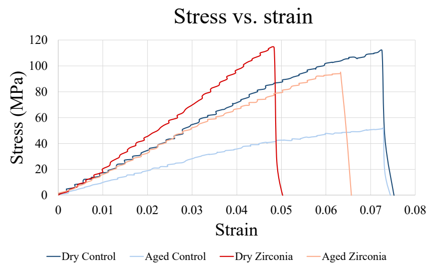


Figure 1 (left): A Verniers Structures Material Tester was conducted at a 4 cm width span. Force and displacement were found in LoggerPro and converted to stress and strain.

Figure 2 (left): A constant force was applied onto samples for 60 seconds at speed 6 on a DeWalt sander.

Results



Graph 1 (left): Stress-strain graph comparing material type and water aging to test composite flexural strength. Units for strain cancel out and are not displayed. Despite the minimal difference in ultimate strength values for dry control and dry zirconia, when exposed to moisture zirconia powder significantly reduced degradation.

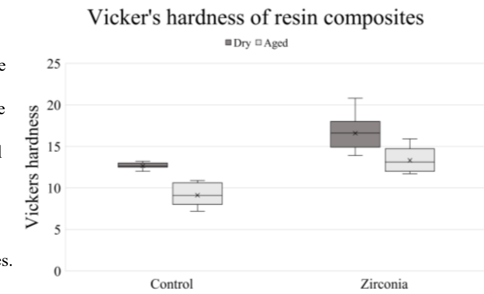
Group	Ultimate Strength (MPa)	Modulus of Elasticity (MPa)	Toughness (MPa)
Dry Control	112 ± 2	1670 ± 50	4.75 ± 0.4
Aged Control	52 ± 2	836 ± 27	2.75 ± 0.3
Dry Zirconia	115 ± 4	2460 ± 21	2.86 ± 0.2
Aged Zirconia	92 ± 3	1540 ± 31	3.60 ± 0.4

Table 1 (above): Flexural strength properties are displayed in the table. Each value was found from the mean and standard error of each property. Ultimate strength is the maximum stress a specimen withstands. Modulus of elasticity is the ratio of stress to strain, and toughness is the area under the stress-strain curve.

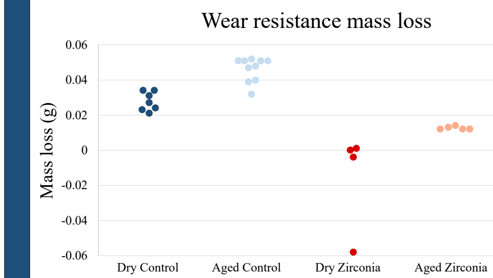
A two-way ANOVA was conducted to analyze the effect of water aging and material type on flexural strength, hardness, and wear resistance. Interactions between material type and water aging significantly affected ultimate strength ($F(1, 35) = 41.61$, $p < .001$) and toughness ($F(1, 35) = 17.05$, $p < .001$), unlike modulus of elasticity ($F(1, 35) = 0.30$, $p = .588$). Material type and water aging significantly affected ultimate strength and modulus of elasticity ($p < .001$); however, simple main effects analysis showed that water aging ($p = .105$) and material type ($p = .17$) had no statistically significant effect on toughness. For flexural strength, zirconia additives reduced degradation caused by water aging as seen in Graph 1, which used data from each sample with an ultimate strength nearest to the values found in Table 1.

There was no statistically significant interaction between the effects of water aging and material type for hardness ($F(1, 16) = 0.07$, $p = .79$) and wear resistance ($F(1, 22) = 0.91$, $p = .349$). Both material type and water aging had statistically significant effects on hardness and wear resistance ($p < .001$). Dry specimens and zirconia composites displayed higher hardness values as seen in Graph 2. Compared to control specimens for wear resistance, water-aged zirconia samples experienced less wear despite degradation (Graph 3).

Results (continued)



Graph 2 (right): Hardness tests were performed with a 200-gram load. The applied force was divided by the total area from each indentation to calculate hardness. Each sample was indented three times.



Graph 3 (left): The negative value for dry zirconia is presumably due to an error with the scale used. This suggests the actual mass loss was minimal.

Conclusion

This study investigated whether the incorporation of zirconia improved dental resin materials after prolonged exposure to moisture. The first two research hypotheses were accepted fully. Zirconia powder improved properties, while degradation from aging worsened mechanical properties. The third research hypothesis was partially rejected as only interactions between ultimate strength and toughness displayed high variation between sample means. Further research can study surface coating by increasing resin particle adhesion. Positive results from future biocompatibility studies could indicate that enhanced resin composites developed in this study can be used to quickly print personalized temporary dental implants in dental offices.

References

Alshabib, A., Silikas, N., & Watts, D. C. (2019). Hardness and fracture toughness of resin-composite materials with and without fibers. *Dental Materials, 35*(8), 1194–1203. https://doi.org/10.1016/j.dental.2019.05.017