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Name of Candidate: MAJ Kaisha Calvin
Master of Science Degree
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USUHS Graduate Dental Education, Advanced Education in General Dentistry- 2 year Program, Fort Hood, TX
Program Director

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Dr. John K. Kreider
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Assistant Program Director

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Dr. Eric C. Hu
USUHS Graduate Dental Education, Advanced Education in General Dentistry- 2 year Program, Fort Hood, TX
Research Mentor

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Date: 2023.06.27 12:54:09 -05'00'

Dr. Paul M. Colthirst
USUHS Graduate Dental Education, Advanced Education in General Dentistry- 2 year Program, Fort Hood, TX
Commander/ Local Dean

Effect of mixing tip size on the porosity and tensile strength of extra light body polyvinyl siloxane impression materials

Kaisha T Calvin, DDS
MAJ, DC, USA
AEGD-2
Fort Cavazos, TX
June 2023

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Kaisha T Calvin, DDS
MAJ, DC, USA
Fort Cavazos AEGD-2 Residency

ABSTRACT

The aim of this study was to compare the tensile strength, porosity, and waste reduction of polyvinyl siloxane (PVS) impression material when using traditional mixing tips and cartridge versus a newly released system. This study used Dentsply Sirona Aquasil Ultra+ Smart Wetting XLV Regular Set PVS Impression Material with the Teal tip (TT) from the previous system, and the Red (RT) and Blue (BT) tips from the new system. Tensile strength was tested by stretching 48 dumbbell samples (n = 15RT, 16 BT, 17TT) in the universal testing machine and porosity was evaluated utilizing micro-CT analysis of cylindrical samples (n = 6RT, 7BT, 7TT). Waste reduction was evaluated by taking the weight of the mixing tips (n =11 per tip) before use and after polymerization. A one-way ANOVA found no statistically significant difference in tensile strength ($p = 0.493$), while a statistically significant difference was found for the modulus of elasticity ($p = 0.0001$). The Tukey-Kramer HSD test showed the statistically significant difference in modulus of elasticity between TT-BT and TT-RT. A Shapiro-Wilk test found the porosity of BT was not normally distributed ($p = 0.013$). The Kruskal-Wallis test determined there was a statistically significant difference in porosity between groups ($p = 0.031$) and the Steel-Dwass method found the statistically significant difference between RT-BT ($p = 0.048$). Waste reduction data utilized the Shapiro-Wilk test and showed TT was not normally distributed ($p = 0.016$). A Kruskal-Wallis test established a statistically significant difference in weight between groups ($p < 0.001$) and the Steel-Dwass results showed a statistically significant difference between RT-BT, RT-TT, and BT-TT ($p < 0.001$). The new cartridge and mixing tip design did result in waste reduction and comparable tensile strengths as stated by the manufacturer. However, the modulus of elasticity was reduced in both the RT and BT, and porosity was increased in the BT.

Keywords*: polyvinyl siloxane***,** *porosity, tensile strength, waste reduction, impressions*

INTRODUCTION

While digital impressions have many advantages and have become increasingly utilized in the crown fabrication process, it is still important to understand and improve conventional impression materials and techniques. Even with advancements in impression materials, there is still no impression material that is 100% accurate.[1] Elastomeric impression materials include polysulfides, condensation silicone, polyether, and polyvinyl siloxane.[1] Since its introduction in 1976, polyvinyl siloxane (PVS), also known as an addition silicone, has been a top choice for clinicians.[2] It provides excellent detail reproduction, elastic recovery from deformation, dimensional stability, and a polymerization shrinkage lower than 0.05%.[3] Clinicians can choose PVS materials without concern for allergic reactions, undercuts, or other disadvantages associated with polyether and polysulfide materials.[4]

PVS impression material comes in a two-part system; a base paste, and an accelerator paste which contains a catalyst.[1] A homogenous mixture of the two is critical to capturing an accurate impression. Three modes of mixing exist: hand mixing, static mixing, and dynamic mechanical mixing.[5] Static mixing is commonly used. It involves using a mixing gun to push the pastes from the cartridge into a mixing tip, resulting in a uniform mixture.[5] Different sized mixing tips are available and selected based on the viscosity of the PVS impression and the amount of material needed for the impression. Regardless of the mixing tip used, a mixture with ideal mechanical properties is desired. These include accuracy, elastic recovery, dimensional stability, hydrophilicity, flowability, viscosity, and high tear energy.[6] The material should be able to withstand stresses to deformation and tearing when removed from both the mouth and model to provide an accurate representation of the intraoral tissue.

In March 2022, a dental manufacturer (Dentsply Sirona, Charlotte, NC) issued a press release announcing a new cartridge and mixing tip system. They stated the new cartridge and tips result in new improved mix quality and a reduction in material waste.[7] They also stated that the new cartridge only requires the material to be bled before the first use, rather than before every impression. As a result, they found waste can be reduced by 64 percent when comparing the new Red Tip (RT) to the previous Teal Tip (TT).[7] The purpose of this research was to evaluate whether the size of the mixing tips used has an impact on PVS impression material properties. While there have been numerous studies on PVS impression materials, limited studies could be found that evaluated differences in the resulting impression based on the size of dispensing tips.

The objective of this study was to utilize the previous PVS cartridge with the Teal helical mixing tip, and compare the tensile strength, porosity, and waste reduction with the same material in the new cartridge with Blue (BT) and Red (RT) mixing tips. The hypothesis is there will be reduced porosity and higher tensile strength in PVS samples mixed from the teal mixing tip. The null hypothesis is that there will be no difference in porosity or tensile strength of PVS samples mixed from any size dispensing tips.

MATERIALS AND METHODS

For all testing, a mixing gun (Dispensing Gun, Dentsply Sirona, Charlotte, NC) was used to extrude the PVS material into the mixing tips.

Testing of Tensile Strength

A standard tessellation language (STL) file of a S2 dumbbell specimen mold according to DIN 53504.2017 was obtained via an open data repository (Zenodo, Geneva, Sweden).[8,9] The file was opened, and supports autogenerated, in a print preparation software (PreForm 3.21.0, Formlabs Inc, Somerville, MA). A 3-D printer was used to print two sets of molds on a stainless-steel build platform (Form3, Formlabs Inc, Somerville, MA) using dental model resin (Dental LT V3 Model Resin, Formlabs Inc, Somerville, MA). Once printed, molds were washed in isopropyl alcohol (Form Wash, Formlabs Inc, Somerville, MA) for 10 minutes to remove excess resin. The molds were dried with compressed air and cured (Form Cure, FormLabs, Somerville, MA) for 5 minutes at 60°C, and supports were removed with flush cutters after processing was complete.

The molds were secured in a tabletop vice to maintain contact, then used to fabricate sixteen dumbbell samples via injection molding with each mixing tip (n = 16). Samples were removed after a 7-minute setting time. Two minutes were added to the 5 minutes recommended by the manufacturer to ensure complete polymerization at room temperature. Excess material was trimmed from samples as needed and placed in a water bath. The samples had a thickness of 2 ± 0.2 mm, a total length of 75 mm with a bar that was 25 mm long. The heads were 12.5 mm wide, and the bar was 4 ± 0.5 mm wide. (Figure 1) Samples were kept in an incubator for 24 hours at 36.9°C to prevent dehydration prior to testing (Forma Series II Water Jacketed CO_2 Incubator, Thermo Fisher, Marietta, OH).

At the time of testing, the width and thickness of each dumbbell sample was measured two times with a digital caliper (EZ CAL IP54, iGaging, San Clemente, CA) and averaged. A stainless-steel ruler was then used to mark two benchmarks on each sample, equidistant from the center, to indicate where it would be clamped for testing. Using a universal testing machine (MTS Alliance RT/5 Machine, MTS Systems, Eden Prairie, MN), samples were secured between pneumatic clamps with care taken to ensure the samples were not in compression or tension. Samples were elongated until failure at a rate of 50 mm per minute at 23°C and 50% relative humidity. The tensile strength data was recorded and calculated with computer software

(TW Elite software, MTS Systems, Eden Prairie, MN), and analysis was completed using a one-way ANOVA and Tukey-Kramer HSD.

Testing of Porosity

A multi-well plate with a flat bottom and lid (Falcon 24-well Clear Multiwell Plate, Corning, Glendale, AZ) was used to make cylindrical samples. The bottom of some wells was removed to allow for easier removal of samples once polymerized. Samples were made with each tip with n = 6 for RT, n = 8 for BT and TT. An additional sample was added to the BT and TT groups as variability was noted in the data. The PVS was injected into the mold, keeping the mixing tip within the impression material as directed by manufacturer.[10] The lid was placed along with a 2 kg weight and samples were removed after 7 minutes. The samples were approximately 20 mm (H) by 16 mm (D). Porosity was measured utilizing with micro-computed tomography (Skycan 1172 MicroCT Control Program version 1.5, Bruker, Billerica, MA). The bottom side of the sample was fixed to the instrument rotating support with double-sided tape. Images were obtained with a pixel size of 16.94µm and a rotation step of 0.70°. For the x-ray beam, a 69 kV setting was used and an intensity of 144 µA. Reconstruction software (NRecon software version 2.0.0.5, Bruker, Billerica, MA) was used to retcon 900 cross-section slices, and porosity was evaluated using analysis and surface rendering software (CTAn Analyzer software version 1.20.3.0, Bruker, Billerica, MA). A Shapiro-Wilk test, Kruskal Wallis test, and Steel-Dwass method were used for data analysis.

Testing of waste reduction

The mass (mg) of all mixing tips were taken on a scale (Analytical Balance, Mettler Toledo XS105, Columbus, OH) before and after use. The mass obtained after use was performed after polymerization. A Shapiro-Wilk test, Kruskal Wallis test, and Steel-Dwass method were used for data analysis.

RESULTS

Tensile Strength

A one-way ANOVA was performed to examine if there was a statistically significant difference in tensile strength between the three MT groups. The results established that there was no statistically significant difference in tensile strength between the different groups (p = 0.493). The mean values (MPa) from the highest to the lowest were TT = 4.07 ± 0.22, BT = 4.02 ± 0.38, and RT = 3.95 ± 0.25. A one-way ANOVA did find a statistically significant difference in the modulus of elasticity ($p < 0.01$) with the mean values (MPa) TT = 3.50 ± 0.26, BT = 3.00 ± 0.09, and RT = 2.93 ± 0.13. A Tukey-Kramer HSD test was used to examine the pair comparisons of the groups. The results showed that there was a statistically significant difference in the modulus of elasticity between TT and BT ($p < 0.001$), and TT and RT ($p < 0.001$), but not between RT and BT ($p = 0.544$). (Figure 2)

Porosity

The results for porosity (%) revealed the mean values from the highest to the lowest as follows: BT = 0.43 ± 0.34, TT = 0.22 ± 0.11, and RT = 0.18 ± 0.10. A Shapiro-Wilk test was completed to check for normal distribution of the data groups. The porosity for the BT was not normally distributed ($p = 0.013$), but RT ($p = 0.435$) and TT ($p = 0.290$) are normally distributed. Due to BT not being normally distributed, the Kruskal Wallis test was used to determine if there are statistically significant differences between the groups. The results established that there was a statistically significant difference in porosity between the different groups ($p = 0.031$). The Steel-Dwass method was used to examine the pair comparisons of the group. The results showed that there was a statistically significant difference in porosity for RT and BT ($p = 0.048$), but no statistically significant difference in porosity between TT and BT ($p = 0.131$) or TT and RT ($p = 0.799$). (Figure 3)

Waste Reduction

Waste reduction (mg) revealed the mean values from the highest to the lowest as: TT = 2689.41 ± 16.28, BT = 2116.92 ± 46.41, RT = 1014.99 ± 15.84. A Shapiro-Wilk test was completed to check for normal distribution of the data groups. The results showed that the weight was not normally distributed for TT ($p = 0.016$) but was normally distributed for RT ($p = 0.066$) and BT ($p = 0.557$). As TT was not normally distributed, a Kruskal Wallis test was performed to examine if there was a statistically significant difference in weight between the different groups. The results established that there was a statistically significant difference in weight between the different groups ($p < 0.01$). The Steel-Dwass method was then used to examine the pair comparisons of the group. The results showed that there was a statistically significant difference in weight between RT and BT ($p < 0.01$), TT and BT ($p < 0.01$), and TT and RT ($p < 0.01$). (Figure 4)

DISCUSSION

The null hypothesis was partially rejected as there was a statistically significant difference in porosity, elastic modulus, and waste reduction. However, tensile strength was comparable among all groups.

While the extra-light PVS material tested was the same formulation and price, the change in design of the cartridge and the mixing tip aimed to save material, improve mix quality, and prevent cross contamination.[7] Per the manufacturer, the TT has a diameter of 8.3 mm ± 0.20 mm (measured at neck), an overall length of 88.5 mm ± 1.0 mm, and an orifice opening of 4.90 mm +0/−0.15 mm. A digital caliper (Dental Digital Caliper, ProDent USA, East Brunswick, NJ) was used to measure the RT and BT as the information was not available from the manufacturer, and not provided upon request. As the new tips are a cube, the diagonal of the square was found by $\sqrt{2}$ x the length of one side, measured at the neck above the wings. The RT has a side length of 6.6 mm - diagonal calculated to be 9.4 mm, an overall length of 59.5 mm, and an orifice opening of 4.4 mm. The BT has a side length of 8.9 mm - diagonal calculated to be 12.6 mm, an overall length of 67.7 mm, and an orifice opening of 5.38 mm.

The waste reduction results of 62% supports the manufacturer's claim that the new RT can reduce waste up to 64% compared to the TT when comparing their low viscosity. However, some differences were noted when comparing the previous tip to the newer tips. The TT has a helical design that mixes the pastes by alternating rotating elements.[3] The new mixing cube technology is credited by the manufacturer with improving the mix quality of the material. The results found no statistically significant difference in tensile strength between the groups but found there was a statistically significant difference in the modulus of elasticity between TT and BT, and between TT and RT. The Glossary of Prosthodontic Terms (GPT-9) defines the modulus of elasticity as "a ratio of stress to strain; as the modulus of elasticity rises, the material becomes more rigid".[11] The study found that the TT had a higher modulus of elasticity, making it more rigid, and possibly more able to withstand deformation. This could be due to the longer length of the Teal tip, which could give the material more time to fully mix.

The study found the BT to have the highest porosity and the RT to have the lowest (Figure 5). The mixing cube technology could possibly be introducing air during the mix due to the larger lumen size on the BT. The BT may perform better with a higher viscosity material. Increased porosity affects the accuracy of impressions and can result in the need for repeated impressions or poor fitting prosthesis. It was possible that this increase in porosity was due to a single clinician error which was a limitation of the study, however the presence of air pockets could be seen on the micro-CT imaging (Figure 5). Another limitation was that the study was in vitro, which does not mimic intraoral conditions.

CONCLUSION

Within the limitations of this study, the results showed that while the tensile strength was comparable between the previous and new mixing tips, the modulus of elasticity was greatest with the previous TT. Porosity improved with the RT. Both the new RT and BT saved on material as claimed by the manufacturer. Based on the results, the RT provided the best combination of strength, porosity, and material savings.

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FIGURES

Figure 1. Dumbbell specimen shown in mold after polymerization, and after removal

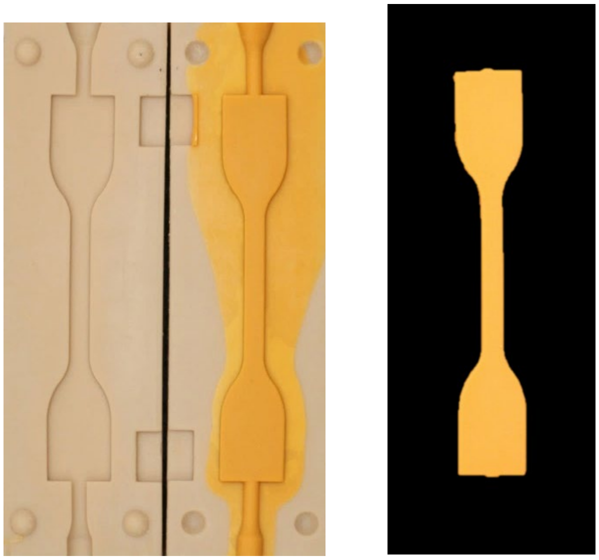

Figure 2. Plot shows comparison amongst tensile strengths and amongst moduli of various polymerized dumbbell impressions, dispensed from different tip designs but made of the same PVS material. Materials with the same case letter are not significantly different (p > 0.05).

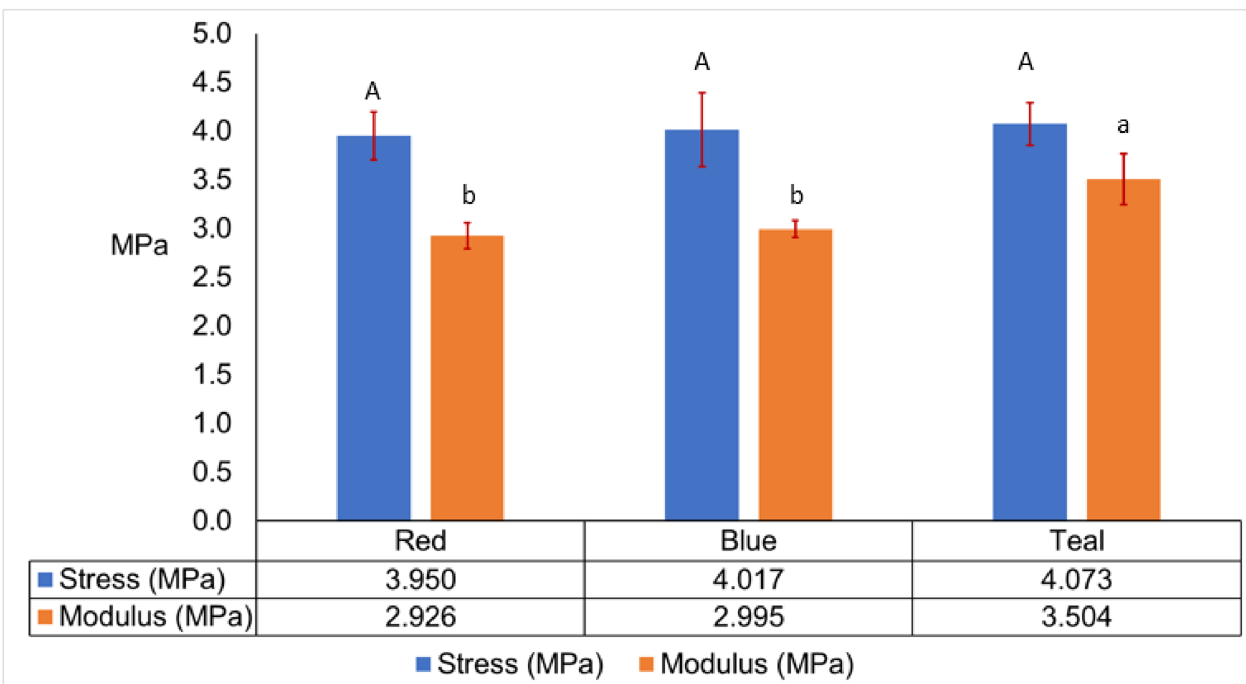

Figure 3. Comparison of the percent porosity of the PVS impression material after extrusion and polymerization using different tip types. Tips with different letters are significantly different (p > 0.05).

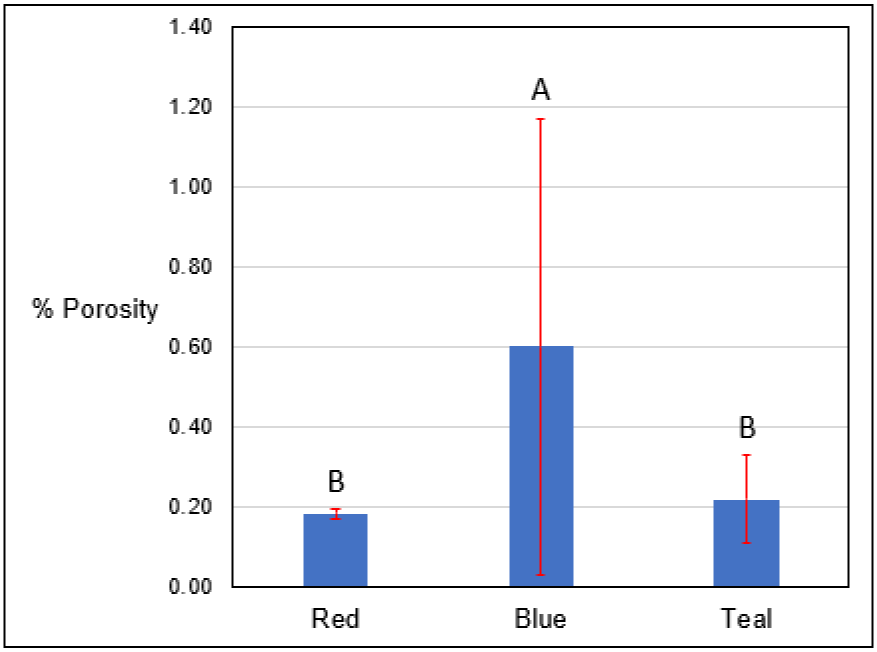

Figure 4. Comparison of the mass (mg) of PVS material retained within PVS impression tips after use. Tips with different letters are significantly different (p > 0.05). The percent difference from the older teal tip is annotated on both the red and blue tip bars.

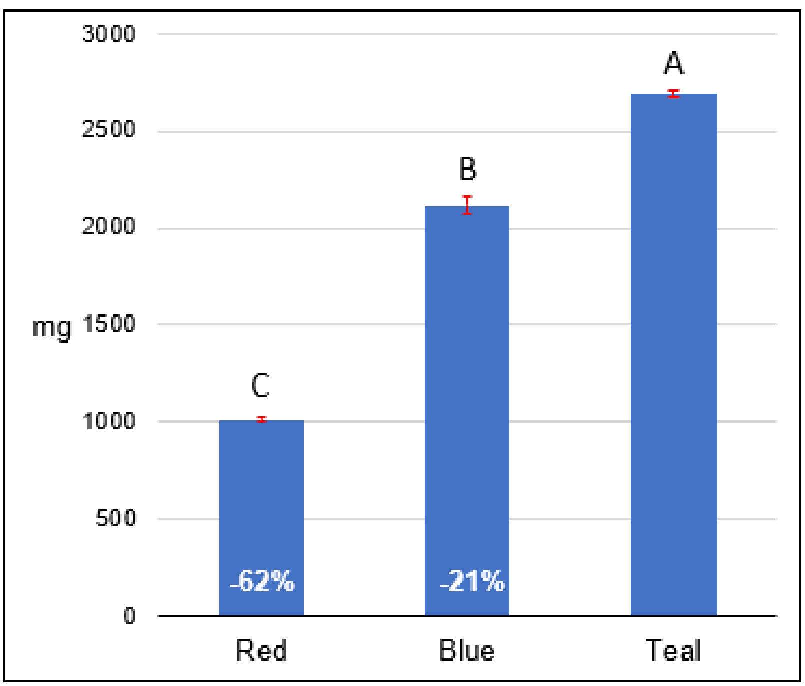

Figure 5. Micro-CT images of porosity samples

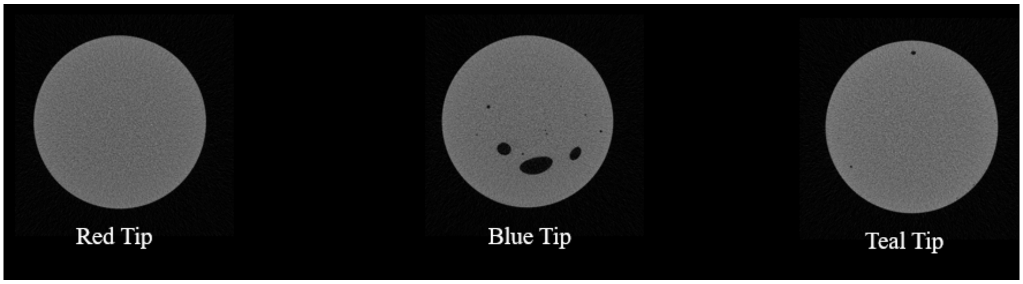

Figure 6. Micro-CT images of mixing tips with polymerized PVS