ULTRASONIC DRY COUPLING THROUGH TISSUE

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1 Introduction

Ultrasonic transcutaneous energy transmission (UTET) is a promising new technology for delivering electrical power to active biomedical implants. A key piece of technology required to make UTET devices viable is a “dry” acoustic coupling that can be worn daily for long periods of time by a patient. The dry coupling must provide a low-reflectance, low-loss, transmission pathway for acoustic energy. For other ultrasound applications such as diagnostic imaging, a coupling gel is typically used to acoustically interface a transducer with the patient. However, in a more permanent application like UTET coupling gel is likely dry out or wash away over time and so a solid-state solution is needed.

In order to reduce reflectance, the dry coupling must have an acoustic impedance as close to that of tissue as possible since this difference between acoustic impedances of two material at an interface is responsible for reflected sound according to equation 1.

$$R = \frac{z_2 - z_1}{z_2 + z_1} \quad \textbf{[1]}$$

Acoustic impedance is the product of a material’s density and its speed of sound.

$$z = \rho * c \quad \textbf{[2]}$$

By manipulating either of these two properties, the acoustic impedance of a material can be controlled.

2 Method

Samples to be tested were manufactured from Dow Corning Sylgard 184. This kit provides a base with a crosslinker. The idea is to manipulate the acoustic impedance by varying either the speed of sound or the density of the sample. The more crosslinked the silicone elastomer, the higher the sample’s bulk modulus which will increase the speed of sound in the material according to the Newton-Laplace equation.

$$c = \sqrt{\frac{K}{\rho}} \quad \textbf{[3]}$$

Where c is the speed of sound, K is the adiabatic bulk modulus, and ρ is the density. Density is increased by mixing ZnO powder into the silicone during the curing process.

Samples were made with the kit’s suggested 10:1 base:crosslinker ratio, as well as a 5:1 and 2:1 ratios. The loaded samples were produced by adding the needed ZnO mass to achieve the desired density. Samples with targeted densities of 1500, 1300 and 1100 kg/m^3 were produced. This results I samples with acoustic impedances ranging between water and unloaded silicone.

The samples were cast in a simple cylinder with tape on the inside to assist in delamination. In order to produce a flat surface on the top of the sample a plug was immersed in the silicone, otherwise surface tension in the silicone would form the top side into a convex surface.

In order to analyse the samples, a pulse-echo technique was used to determine the amplitudes of echoes reflected off the sample’s front and back face and the time of flight between echoes. The pulse was created using a signal generator, sent into the transducer, through deionized water into the sample, reflected off a glass slide, amplified, and then to an oscilloscope.

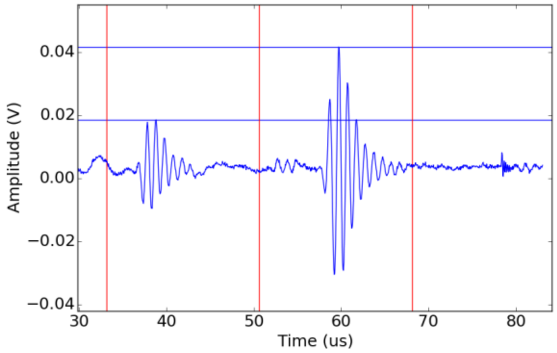

Figure 1: Front and Back Face Echoes of ZnO Loaded Sample with Maxima

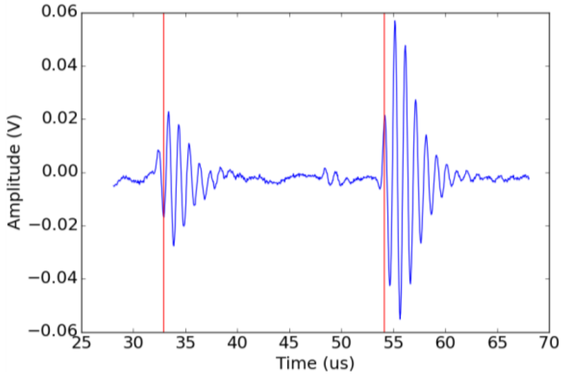

Figure 2: Echoes Measured from Crosslinked Sample Showing Points Used to Determine Time of Flight

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The pulse must travel through the length of the material twice before the 2nd echo reaches the transducer behind the first echo. The speed of sound can be found by dividing twice the length of the sample by the difference in time between the start of each echo.

3 Results and Discussion

The speed of sound of the samples with varying amounts of crosslinker is shown in Figure 3. Increasing the amount of crosslinker has a negligible effect on the speed of sound. IT is likely that the kit's suggested 10:1 ratio of base to crosslinker is the point where the silicone becomes fully crosslinked and no amount of additional crosslinking agent will further stiffen the material. It is likely that reducing the amount of crosslinker will result in a less stiff silicone, however, this is not useful for increasing acoustic impedance.

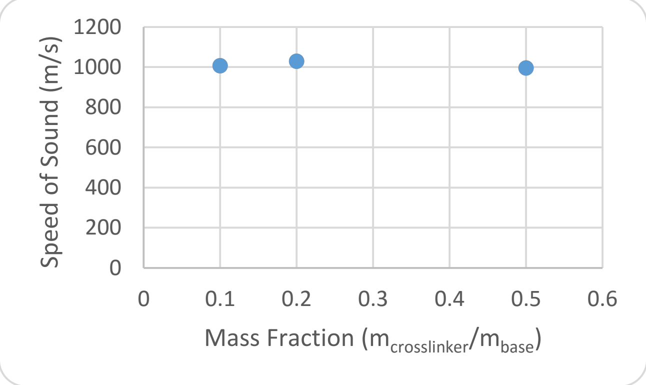

Figure 3: Speed of Sound in Silicone with Increasing Amounts of Crosslinker

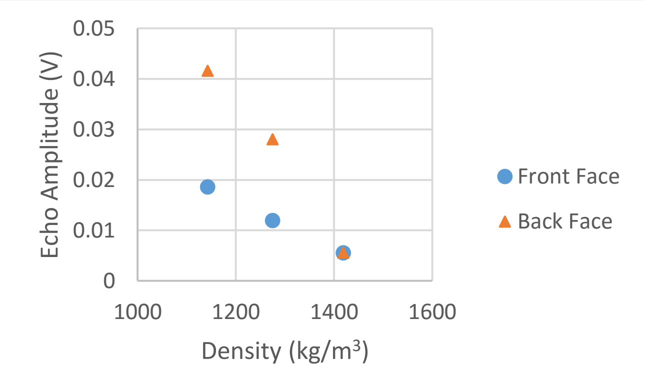

Figure 4: Maximum Amplitude of Front and Back Face Echo vs Composite Density

Figure 4 shows the maximum amplitudes from the echoes off the front and back faces of the samples loaded with ZnO. The back face echoes are much stronger because the sample was placed on a glass slide which has a very high acoustic impedance and therefore reflected nearly all the sound that came from the sample which had a much lower impedance. The sample and the water had much more closely matched acoustic impedances which is why a much weaker echo was reflected back to the transducer. It is evident that, as the samples increase in density due to ZnO loading, the reflected pulse off the front face becomes weaker. This suggests that ZnO loading increases does in fact increase the acoustic impedance as the samples with more loading are more closely matched to the water.

Figure 4 also shows a drawback however, the more closely matched, higher density samples should have increasingly strong echoes off the back face as more sound is transmitted through rather than being reflected back. The reason the back face echo is decreasing is due to attenuation introduced by the addition of the ZnO powder. The small granules of ZnO are large enough to interfere with the sound and create losses due to internal reflections within the sample. This puts an upper limit on the thickness that the dry coupling layer can be as well as the amount of loading that can be done.

4 Conclusion

Silicone as a material for coupling ultrasound to tissue is a viable material. In order to optimise the material to get the maximum amount of sound energy delivered into living tissue, losses from reflectance and attenuation must be minimized. This work has shown that for Sylgard 184, the maximum speed of sound is approximately 1000m/s and this cannot by surpassed by adding more crosslinking agent during curing.

It has also been demonstrated that ZnO powder can increase the acoustic impedance of the silicone by forming a composite material with a higher density than the silicone alone. There is a drawback in that the composite is much more attenuating and this attenuation increases as the concentration of the ZnO power increases in the composite. Attenuation losses can be mitigated by making the coupling layer as thin as possible as attenuation is also a function of the length of material that the sound must travel through. This suggests that an optimal solution may exist consisting of a thin layer of ZnO loaded silicone that balances losses due to reflection with those due to attenuation.