Concept design for use in a thin and protective phone case

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Introduction

This project aimed to find a viable concept design for impact-resistant phone cases under 1.3 millimeters thick. The energy absorption required from this design would be about two joules in the interest of protecting a phone from a one-meter drop. In order to distribute this energy, a hexagon-based pattern structure was designed in a soft material layer to serve as failure points for the flow of the silicone. Silicone's viscoelastic properties and strong siloxane bonds make it a suitable material for absorbing energy. These failure points, as shown in figure 1, should increase the shock-absorbing capabilities of the design (Caserta et al., 2011). Another material of interest was a polyethylene-based fiber system called Dyneema, which has ballistic-resistant properties, making it a viable material choice for a phone case design. Dyneema's high tensile and compressive strength resists impact penetration due to the strong chemical bonds in the polyethylene. This property would stop any sharp surfaces from penetrating the outer layer and damaging the phone (Sockalingam et al., 2017). Another material known for its high strength to weight ratio was carbon fiber. The carbon bonds that make up the material are strong and provide a lightweight yet robust nature (Petrů et al., 2016). These various materials were then combined in order to form a thin multi-layer design.

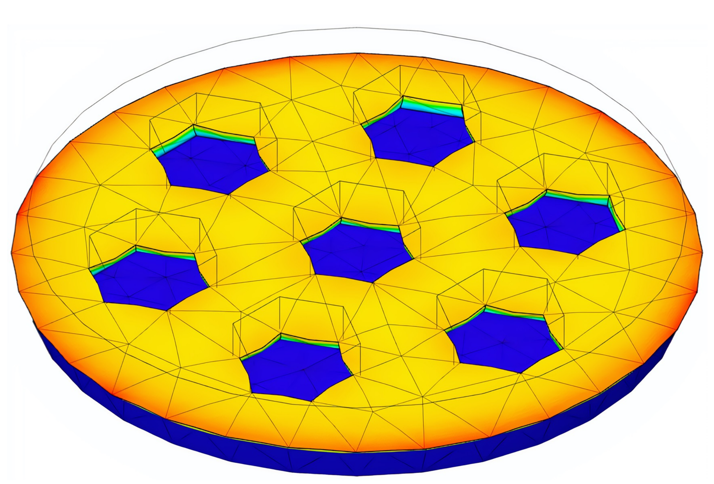


Figure 1 (left): The simulation in Autodesk Fusion 360 shows the deformation expected from compression and how the silicone will utilize failure points to flow. The wireframe shows the original shape of the object. The orange depicts the areas of higher deformation, and the blue depicts the areas of low deformation. The image is magnified, and the final cut sample has a diameter of 25 mm.

Methods and Materials

Specifications were modeled for three design variations in Autodesk Fusion 360, with disk diameters of 25 mm, as shown in figure 2. Silicone honeycomb disk layers were cut by a laser cutter. Carbon fiber disk layers were cut using household scissors, and the Dyneema disk layers were cut using custom toothed scissors supplied by the Army Research Laboratory. The layers were assembled into three designs (with a set of eight samples for each design): silicone honeycomb and solid carbon fiber (SCF), solid Dyneema and solid carbon fiber (DCF), and a trilayer design made with two layers of Dyneema and one layer of carbon fiber in between (TCF). The multiple layers of each sample were bonded by super-glue (cyanoacrylate). The machine used for testing the samples was a Materials Testing Systems (MTS) servo-hydraulic load frame, a high-strain rate uniaxial machine. All samples were compressed to 80% strain at a rate

Methods and Materials (cont.)

of 100 per second (100 times the sample height per second). The curves for each set of samples were then averaged together to see how the failure between the designs compared, as shown in graph 1. Then, one sample from each set was compressed four times to see if there was any change in the curve indicating damage, as shown in graph 2. The integrals (energy in joules) of the raw data curves were calculated. The integrals for each design set were then compared visually as shown in graph 3 and statistically compared using a Kruskal-Wallis non-parametric test.

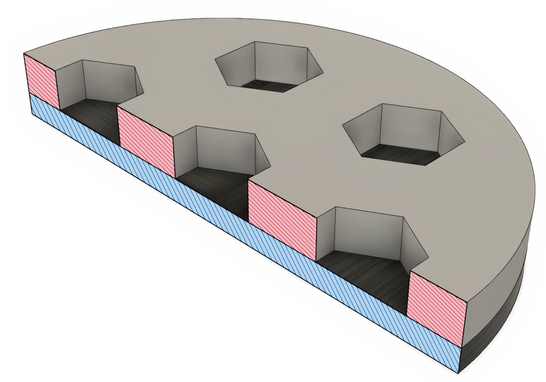
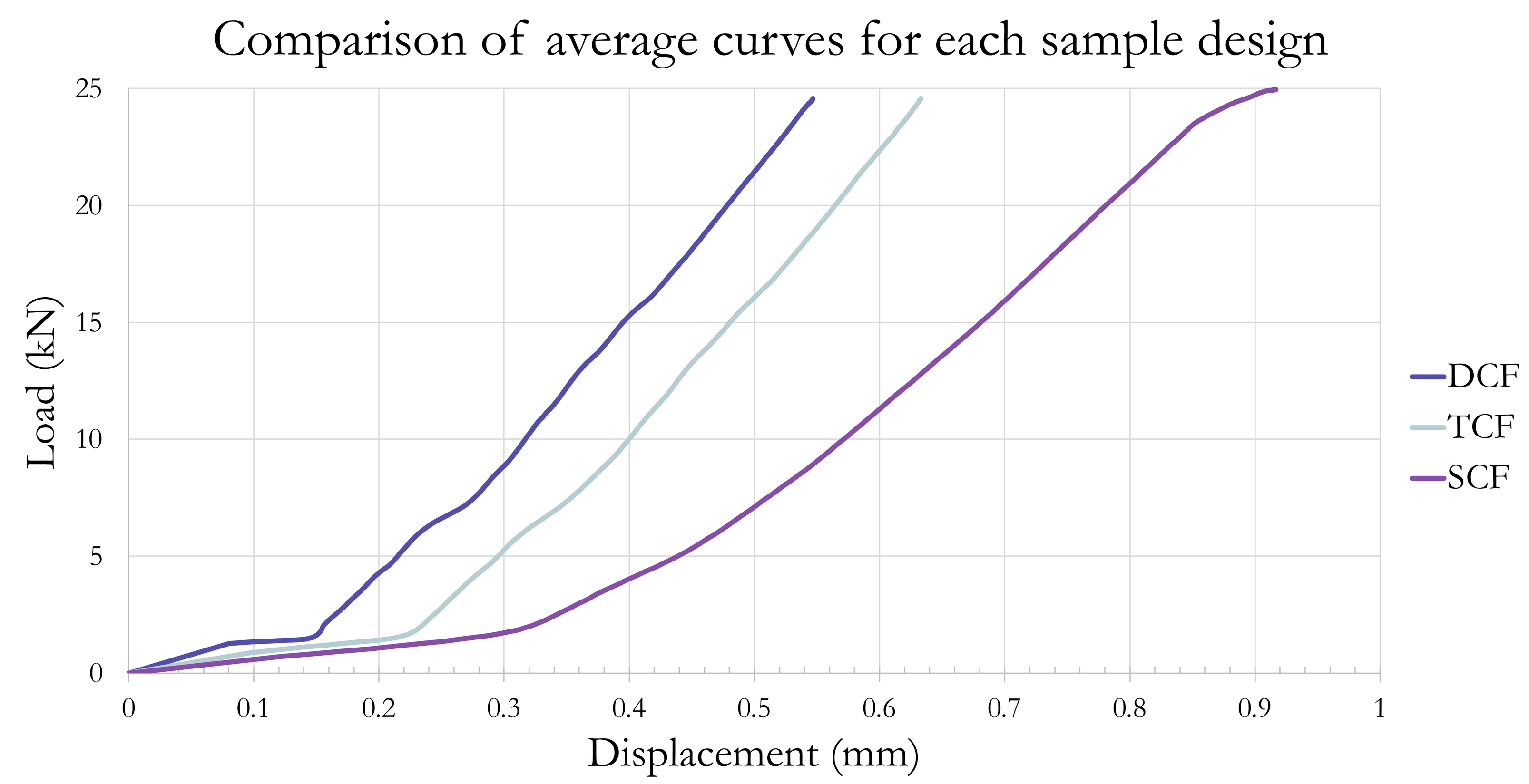
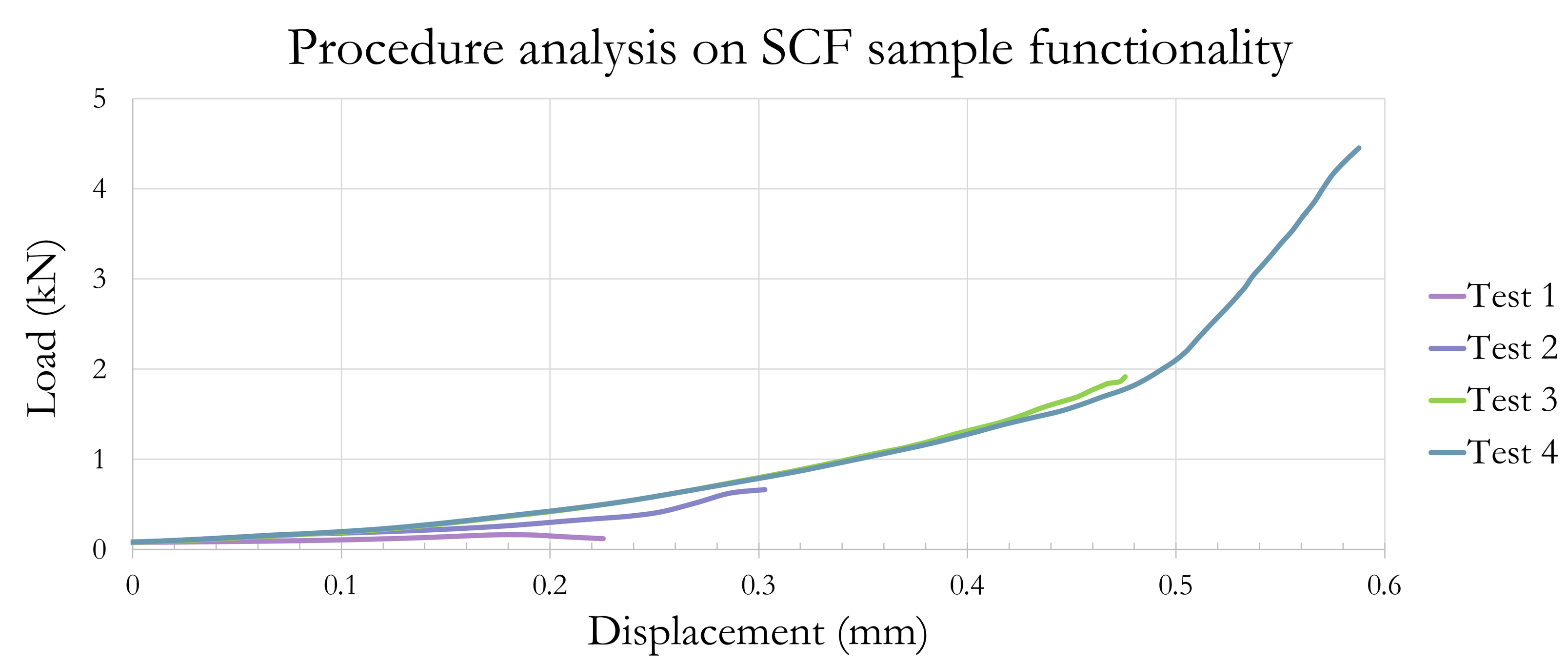


Figure 2 (left): The three-dimensional model of the SCF bilayer samples shows the hexagon-based pattern structure in the silicone layer (pink) of the sample with the bottom carbon fiber layer (blue). The image is magnified, and the final cut sample has a diameter of 25 mm.



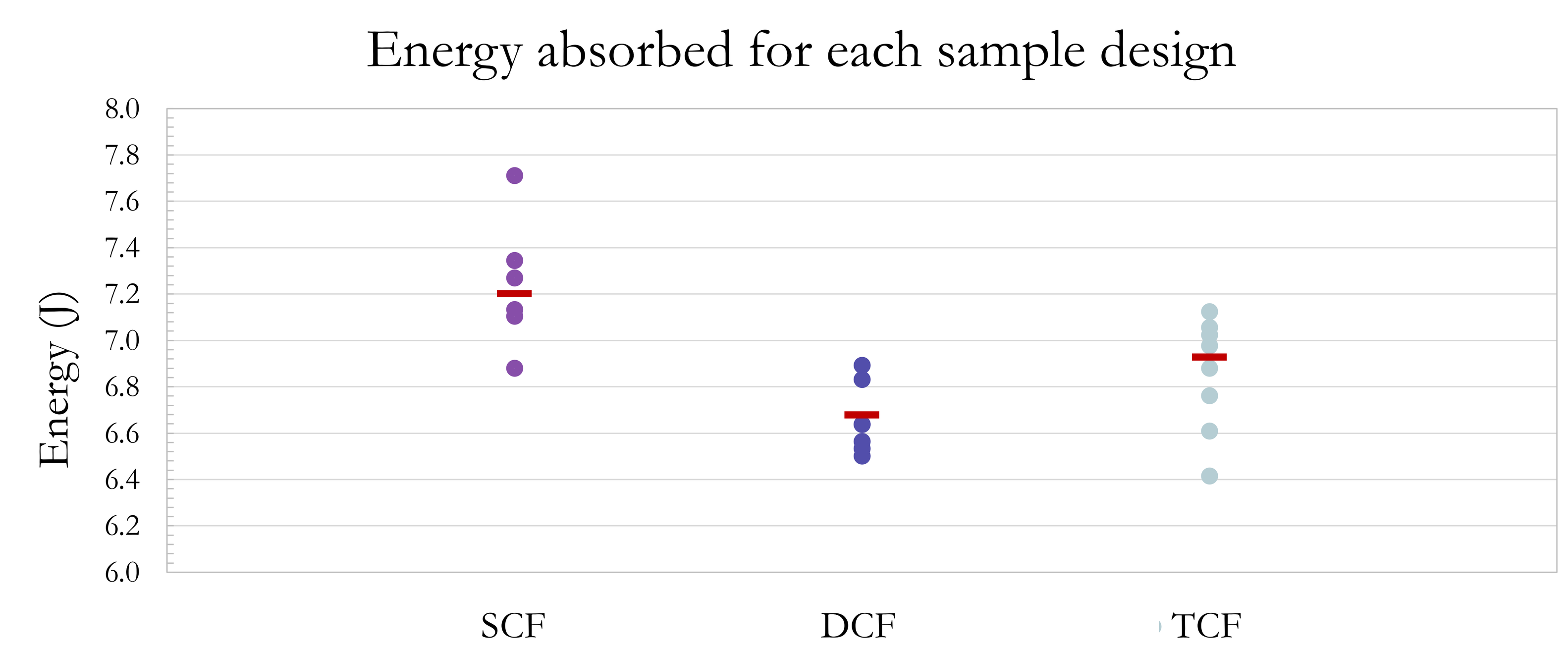
Graph 1 (above): Each design's 15-point moving average curve is depicted above. These were derived from mean load-displacement curves for each set of sample tests (DCF n = 7, TCF n = 8, SCF n = 6). The SCF design reached the highest strain due to the viscoelastic properties of silicone.



Graph 2 (above): The graph shows the results from four consecutive tests on the same SCF sample calculated using a 15-point moving average. The lines are in order of increased displacement, following each other and overlapping, confirming there was no damage to the sample. This was repeated for each design with similar results.

Results

Graph 3 shows that all three designs were functional, absorbing more than two joules. A Kruskal-Wallis test showed that the energy absorbed for each design was different, $H(2) = 10.96$, $p = 0.004$. The SCF design (Mdn = 7.2, n = 6) absorbed more energy than the DCF (Mdn = 6.6, n = 7) and the TCF designs (Mdn = 6.9, n = 8). The SCF design was the most successful in absorbing energy. Repeated tests on all sample designs indicated a minimal loss of strength (an example is shown in graph 2). The curves analyzed from each set of samples tested indicated that the failure was nearly all plastic for all three sample designs.



Graph 3 (above): Shows the energy absorbed for each design. The median (red bar) for the SCF is the highest, but the SCF also has the highest range despite it possessing the smallest sample size of the three designs.

Conclusion

The objective of the project was achieved by finding a successful structural and material design that was under 1.3 mm thick and could absorb two joules. The results of this experiment show that all three designs are viable for use. The optimal design is dependent on operational preference, for instance, the Dyneema and carbon fiber sandwich was the thinnest of the three designs, whereas the silicone honeycomb was the most protective. This thin yet energy absorbent design could be extended to various impact-resistant applications such as personal protective gear and encasement for other shock-prone electronics.

References

Caserta, G. D., Iannucci, L., & Galvanetto, U. (2011). Shock absorption performance of a motorbike helmet with honeycomb reinforced liner. *Composite Structures, 93*(11), 2748–2759. https://doi.org/10.1016/j.compstruct.2011.05.029

Petrů, M., Ševčík, L., Lufinka, A., & Syrovátková, M. (2016). Experimental analysis and study of the shock absorption of carbon composite. *Applied Mechanics and Materials, 827*, 157–160. https://doi.org/10.4028/www.scientific.net/amm.827.157

Sockalingam, S., Casem, D., Weerasooriya, T., McDaniel, P., & Gillespie, J. (2017). Experimental investigation of the high strain rate transverse compression behavior of ballistic single fibers. *Journal of Dynamic Behavior of Materials, 3*(3), 474–484. https://doi.org/10.1007/s40870-017-0126-2