OSJ | OPEN SCIENCE JOURNAL

SHORT ARTICLE

An Environmentally Viable Helmet Design Using Low Impact Material

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OPEN ACCESS

Citation: Tahk Y., Tahk Y.W. (2022) An Environmentally Viable Helmet Design Using Low Impact Material. Open Science Journal 7(2)

Received: 27th February 2022

Accepted: 18th April 2022

Published: 13th June 2022

Funding: The author(s) received no specific funding for this work

Competing Interests: The authors have declared that no competing interests exists.

Abstract:

In utilizing Young's Modulus to determine the elasticity of a material as well as the protecting structure of the human brain, we experimented with various materials to find the most inelastic material that would allow for maximum protection of the brain. Due to the low Young's Modulus Value presented in Agarose Gel and Silica Aerogel, these would be a viable option for a thin, viscous layer of protection inside the helmet. Using an impact car to mimic a head-on collision, we tested agarose gel, silica aerogel, polystyrene, and wood by measuring acceleration and the time duration with the Arduino Science Journal. The objective was to find which material would be the most viable options to create an environmentally safe alternative to polystyrene while maintaining the integrity of the helmet during a collision. Both Silica Aerogel and Agarose Gel had similarity to polystyrene while being a much more environmentally viable option due to their ability to decompose quickly. Agarose Gel is less favorable because it dries up quickly, requires heat to activate, and is prone to breaking. Silica Aerogel is the best option to make the football helmet protectant because it is extremely light, a thermal insulator, and is less prone to breakage.

Keywords: Impact; Helmet Design; Environmentally Safe

Introduction

The paper, *Design of Armor for Protection against Blast and Impact* [1] by Tanaz Rahimzadeh, Ellen M. Arruda, and M.D. Thouless from the University of Michigan – Ann Arbor, studied the usage of impulse on various materials using a model of a football helmet to create a new design that contains blast armor elements. Impulse is the change in momentum, otherwise defined as the product of force and time of duration. To expand upon this idea, we designed a football helmet that would utilize environmentally safe materials in the place of polystyrene while reducing the impact. To reduce the impact, we modeled the design of the helmet after the design of the brain. The brain is created with three layers of membrane that protect both the brain and the spinal cord. The inner layer of the brain is called the pia mater, or in our experiment would be modeled after the brain of the person themselves. The middle layer of the arachnoid is a web-like structure filled with fluid that allows for cushioning of the brain, and we emulated this structure by experimenting with silica aerogel and agarose gel. The outer layer of the dura mater mimics the same plastic material traditionally found on helmets [2]. An inelastic material is one that has low impact, can easily be deformed, and has a lower Young's Modulus value. Young's Modulus Theory is the property of how easily a material can stretch and deform or defined as the ratio of tensile stress to tensile strain [3]. To choose a material, we observed materials that would stretch well and had both elasticity and plasticity. We took inspiration from breast implants, which are most commonly filled with silicone aerogel because human exposure to silica aerogel particles has been shown to be harmless [4]. We chose a silica aerogel that has a Young's Modulus value of 0.106 kPa [5]. Another option was agarose gel 1% which has a Young's Modulus value of approximately 38 kPa [6]. Both materials have extremely low Young's Modulus Values which allows for them to be easily deformed and quite inelastic. Our aim when creating this collision experiment was to find a material that would replace the polystyrene traditionally found in football helmets with a more environmentally safe option while maintaining the integrity of the helmet. The density of polystyrene is given as approximately 28-34 kg/m^3 [7], the density of aerogel is 3 kg/m3 [8], and the density of agarose is 1,033 kg/m^3 [9]. The density of aerogel is smallest, therefore the most viable compared to that of polystyrene and agarose. Current experimentation has not been done in the usage of silica aerogel into helmet, with the industry sticking strictly to a model of plastic. There has been little to no investigation to prove the comfort, and protection of the wearer of the helmet and the aerogel provides an innovative approach to develop a greater helmet model. The Young's Module of Silica Aerogel is comparable to polystyrene and the silica aerogel is an environmentally safe alternative.

Materials and methods

To set up the experiment, place two books each at opposite ends of a table. Place the 2.2 m Aluminum Dynamics Track (ME-9779) (PASCO scientific, CA) between the two sets of books. Tape a smartphone with Arduino Science Journal (Arduino, MA) to the top of an Impulse Cart (PASCO scientific, CA) firmly using a long piece of masking tape and make sure the phone is secure as shown in Figure 1.

Fig. 1

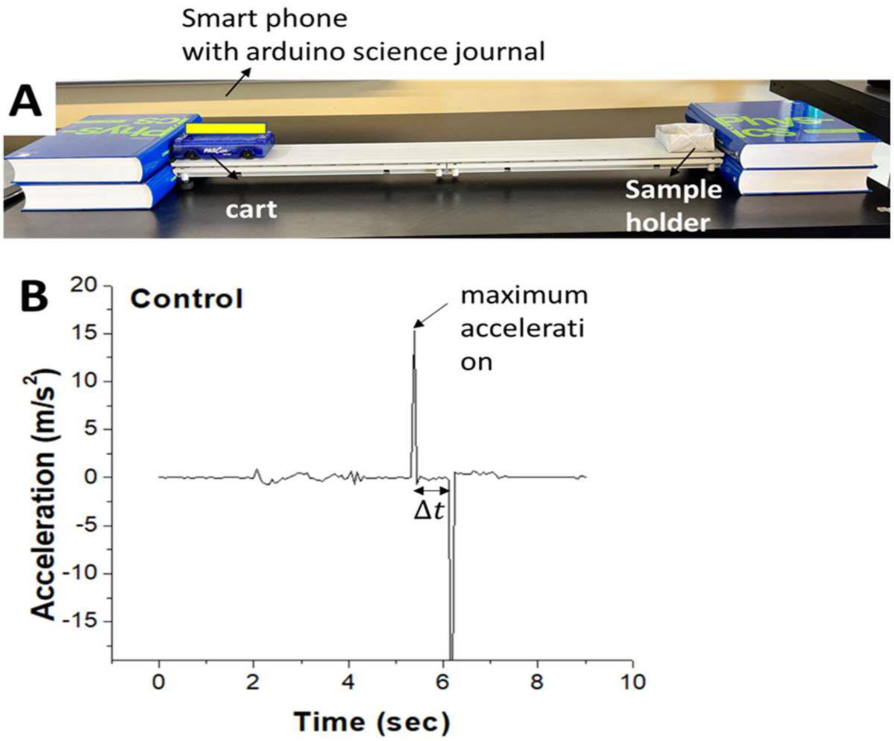


Figure 1. Diagram of Experiment Setup and Acceleration Measurement, Sample Measurement by the Arduino Science Journal

The Arduino Science Journal is a free and open source that allows for data gathering by using smartphone sensors in tandem with sensors connected to either the Arduino App or a third-party app. The data is strictly measured for the change in the Y-axis as the X-axis can be disregarded. The minimum and maximum acceleration is given with a table of data values generated. Construct boxes of paper (sample holder) and tape together at the corners as shown in Figure 1A.

Leave one material box empty and fill 3 material boxes each with amounts (5g) of Polystyrene (BM Solutions LLC, NJ), E-Gel Go! Agarose Gels 1% (Thermo Fisher Scientific, CA), Wood Box (Michaels, TX) and Silica Aerogel (Stemcell Science Shop, OK). The agarose gel is premade, and the silica aerogel comes in particle form. Place materials inside the boxes, making sure that the material does not overflow. Weigh each material, with the box, on a scale and note the measurement in grams. Measurements are taken to the nearest +/- 0.1 g on the scale, using the Ohaus PX2202/E Pioneer Precision Balance (Data Support Company, CA). Place the boxes with materials at the left end of the ramp as shown in Figure 1A. Set the cart at the right end of the ramp as shown in Figure 1A. Ensure that the spring used is pushed in all the way for a consistent velocity. Ensure that the Arduino Science Journal is recording in y-direction measuring acceleration of the cart. Push the button to release the car and record measurements for acceleration and time. Run an initial experiment with the empty box to get a baseline of the stopping force. Then switch out the boxes after each iteration. From this, calculate the force of the car and impulse of the collision between the car and the material box as following equations:

$F = ma$ (1)

where m is the mass of the cart plus sample material and a is the acceleration (maximum acceleration is measured as the acceleration as shown in Figure 1B).

$I = F\Delta t$ (2)

where F is the force measurement from Equation 1 and Δt is time lapsed for the collision (Δt, dimuration time is defined in Figure 1B).

Results

When creating this collision experiments to find a material that would replace the polystyrene, there was experimentation with more environmentally safe materials while maintaining the integrity of the helmet. The experiment was set up to measure maximum acceleration and time duration using the Arduino Science Journal as shown in the Materials and Methods.

Fig. 2

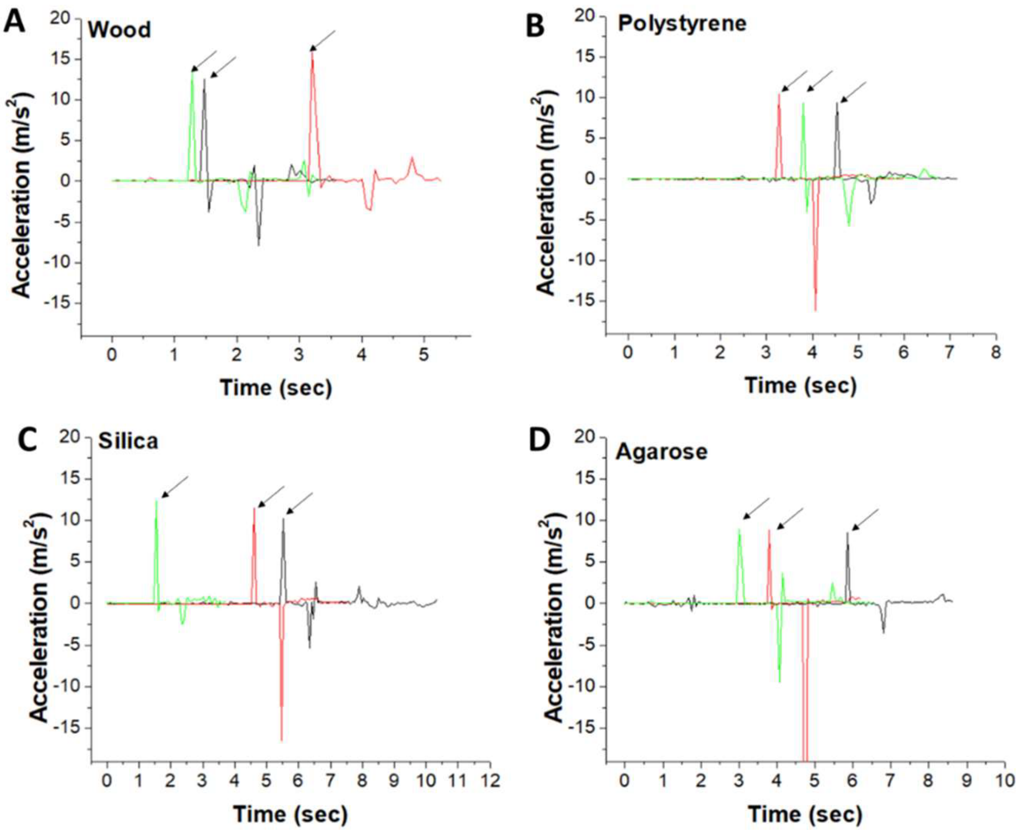


Figure 2. Acceleration vs. Time Measurement Graphs for Wood Block (A), Polystyrene (B), Silica Aerogel (C), and Agarose Gel (D)

As shown in Fig. 2, the Acceleration vs. Time Measurement for Wood Block (A), Polystyrene (B), Silica Aerogel (C), and Agarose Gel (D) were measured and arrows point to maximum accelerations. The acceleration of the impulse crash cart simulates a real-life collision under controlled and minimized circumstances. The wood was utilized as a control material due to its relatively elastic nature that was greater than the other elements we measured. The calculations and measurements were summarized in Table 1. The maximum acceleration of wood was the largest (14.0 ± 1.62 m/s^2), while silica aerogel (11.4 ± 1.05 m/s^2), polystyrene (9.7 ± 1.15 m/s2), and agarose gel (8.8 ± 0.26 m/s^2) were significantly lower than that of the wood. Newton's Second Law states that force is a product of the mass of an object and the acceleration of an object. The mass is held constant (5.0 ± 0.1 g) while the acceleration changes each iteration. Thus, the minimal force among the materials tested is needed to minimize the impact of the collision. The impact force of wood was the largest (0.07 ± 0.008 N), while silica aerogel (0.057 ± 0.005N), polystyrene (0.049 ± 0.034 N), and agarose gel (0.044 ± 0.002 N) were significantly reduced compared to the wood. Momentum is the product of the mass and velocity of an object. The duration times for each sample were obtained as 0.88 ± 0.04 s for wood, 0.84 ± 0.13 s for polystyrene, 0.82 ±0.04 s for silica, and 0.98 ± 0.08 s for agarose respectively. The smaller force is needed for the smaller impulse, which indicates the amount of bounce-back that a person would have after a collision or how well a helmet is able to absorb the force of impact during the collision. Thus, the impulse of wood was obtained as 0.062 ± 0.0076 N·s, while silica aerogel (0.047 ± 0.0050 N·s), agarose gel (0.043 ± 0.0038 N·s), and polystyrene (0.041 ± 0.0070 N·s) were significantly lower than wood. A statistical graph of box chart in Impulse Measurements for Each Sample is shown in Fig.t3.

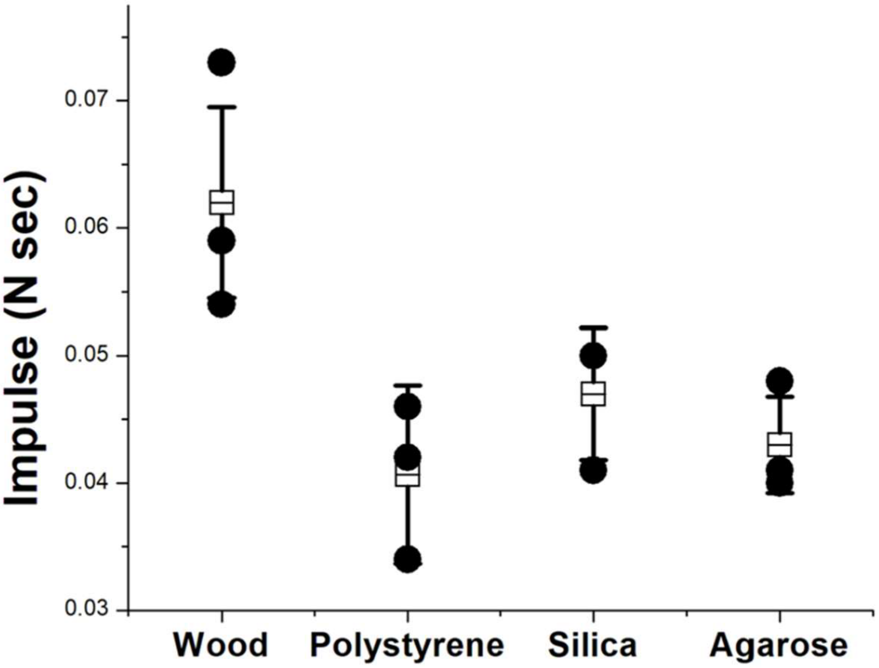
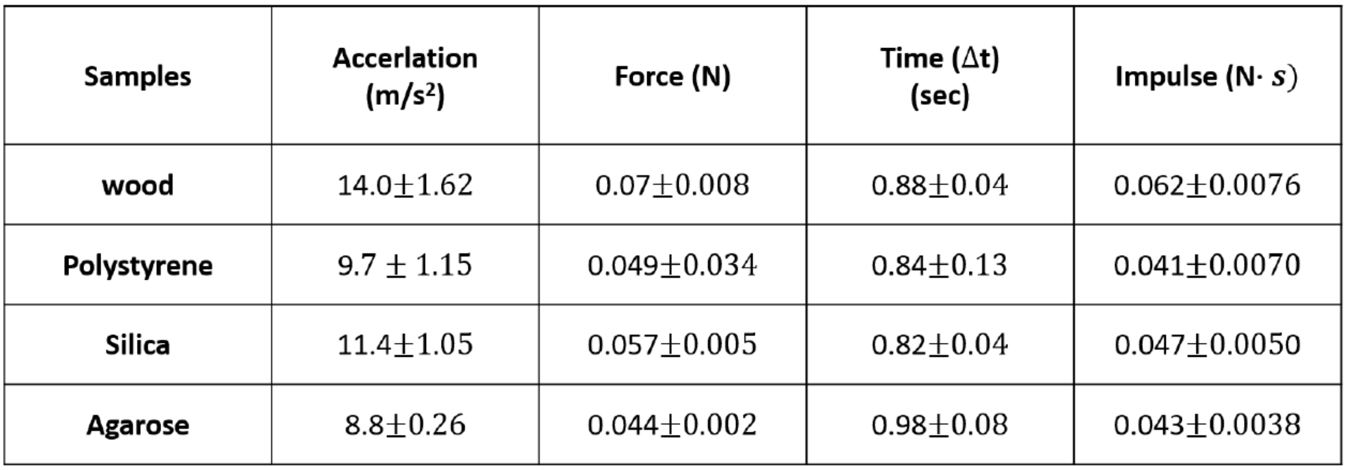


Figure 3. Impulse Measurement for Each Sample. n=3 for each sample p values for Impulse Measurement in comparison to wood box (unpaired t-test). * $p < 0.05$, ** $p = 0.08$

The impulse values for polystyrene, silica, and agarose were significantly reduced than the wood. The p values for polystyrene and agarose were < 0.05 and the p value for silica was 0.08.

Table 1. Calculations of Force and Impulse Based on Acceleration and Time Measurement (n=3)



Samples	**Accerlation (m/s^2)**	**Force (N)**	**Time (Δt) (sec)**	**Impulse (N· s)**
wood	14.0±1.62	0.07±0.008	0.88±0.04	0.062±0.0076
Polystyrene	9.7 ± 1.15	0.049±0.034	0.84±0.13	0.041±0.0070
Silica	11.4±1.05	0.057±0.005	0.82±0.04	0.047±0.0050
Agarose	8.8±0.26	0.044±0.002	0.98±0.08	0.043±0.0038

Conclusion and discussion

The usage of a helmet is diverse, playing key parts in transportation (as most states require a helmet to be worn when biking or scootering), in the sports industries, in construction (as a hard hat has a similar structure to that of a helmet), and many other key industries where the preservation of an individual's health is paramount. Helmets also play an important role in military situations, providing significant protection against blast-impact in the field. Although the initial focus was a football helmet, the results of this study extend far beyond solely football and can also be applied to other activities requiring a helmet. More specifically, football has proved to be an integral part of American culture and franchises are often built around players and the successes of teams. To extend the longevity of a player's career as well as minimize injury to the brain, experimentation was conducted to mimic on a smaller scale the collision between players and the important role that a helmet plays.

The study was initially conducted based upon a simulation run of the experiment conducted at the University of Michigan. Performed in a high school classroom, it lacked the sophistication and materials required to fully mimic the experiment, but instead replaced the technical elements with simpler ones, such as a phone app instead of a sensor to measure the acceleration. It was intriguing to see the design of the helmet slightly changed, because for so long they had seemed bulky and unnecessary objects. Now, understanding the motivations and scientific principles behind the design of the helmet sparked an interest in advancing with an investigation of design improvement. Further investigation, not able to be currently conducted due to the author's limited access to materials, should be conducted into the amplitudes and frequencies that are produced during and after a collision, to successfully measure how successful the design of the helmet was by analyzing the waves. Further investigation should also be conducted into the conductivity of the materials as to test how compatible the materials are in a heat and pressure situation. Although the agarose gel had the smallest force value as well as acceleration, its time was significantly greater than the other materials tested. This would have caused for a slightly larger impulse value than indicated meaning that it would be largely similar to the polystyrene values for acceleration, force, and impulse. This can be attributed to both human error when working with the Arduino Science Journal as well as the car derailing (accounting for the x-direction), which would affect the impulse calculation as the collision is no longer elastic. The results demonstrates that an agarose gel would be a viable alternative to the polystyrene present in helmets due to the similar success in absorbing impact. However, the nature of agarose gel requires heat to be present as well as the fragility of the material which causes frequent fractures and compromises the structural integrity of the material. Both silica aerogel and agarose gel are much more environmentally sustainable compared to polystyrene due to the shorter time period required for full decomposition of the material. Polystyrene has also been known to add harmful chemicals to the environment during the decomposition process while both silica aerogel and agarose gel are safe for humans to touch and dispose of. The silica aerogel had slightly greater values of acceleration, force, and impulse compared to the values of polystyrene, but it is worth noting that the values were nearly similar which indicates that it would be a viable candidate for the helmet. An argument presented for the silica aerogel is the nature of its composition.

Compared to the more brittle nature of agarose gel, the silica aerogel is stronger as indicated by the Young's modulus value of 0.106 kPa compared to agarose of 38 kPa [6] . Silica Aerogel is also hydrophobic which provides a repellent from bodily liquids that might become present in the helmet as well as a thermal insulator which allows for it to keep out external heat while insulating the head with natural body heat. Even though the p value for silica aerogel ($p = 0.08$) is slightly higher than the polystyrene ($p = 0.03$) and agarose ($p = 0.04$) compared to wood as shown in Figure 3, it is comparable to polystyrene and replaceable.

The data suggests that agarose gel and polystyrene have similar impulse values meaning that the impact will be extremely similar for both materials while the silica aerogel is slightly greater. All materials have similar values and are thus weimpll suited for impact absorption, but the ideal replacement for the polystyrene found in football helmets was silica aerogel due to its thermal insulation, light weight, and lower Young's modulus. The Young's modulus provides an inelastic material due to its low value of 0.106 kPa. Compared to agarose gel which is more prone to breaking and requires a heat source, the silica is much more viable. The thermal insulation allows for cooler body temperatures during the heat of summer which offers another layer of protection for the brain. Further studies to remedy the discrepancy would include integration of existing silica gel with fiberglass to allow for strengthening of the material and thus withstand a collision better.

Acknowledgements

The author would like to thank Boyoung Cha, PhD (Portal Bioscience, LLC) for his work with data analysis and reading the manuscript.
Also, the author would like to thank Kathleen Shreve (Homestead High School) for graciously allowing use of materials and experimentation.

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Figure legends

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