Project Team

NOLAN HORGAN
horgan@purdue.edu
B.S. Mechanical Engineering '22

DANIEL HARRINGTON
harrind@purdue.edu
B.S. Mechanical Engineering '23

ANNA GIESLER
giesler@purdue.edu
RESEC Director

Shear thickening fluids in soles: Impact Damping

• STF • Shear rate • Energy

Spring 2022

It is often quite easy to observe the swift advancements in industries, such as internet tech or medicine, rolling out new products with each passing year. These advancements are less obvious in athletics as the rules often remain stagnant as a courtesy to both the fans and players that enjoy it. The most noticeable changes come in the form of broken records, which begs the question: Are the today's athletes really better than those of the past? While there may be some merit to this, another factor is that the equipment surrounding the athletes has improved dramatically. Specifically, the focus of this project is on advancements in athletic footwear in basketball and volleyball. These sports heavily rely on jumping motions to achieve desired outcomes, such as dunking or spiking.

Therefore, a shoe that can efficiently transfer energy through the athlete to increase their vertical jump is highly desirable. Unfortunately, this comes at the cost of safety because the shoe is less capable of cushioning a landing. This is where shear thickening fluids (STFs) comes in play. STFs are some of the only compounds capable of acting as both a spring and a damper. The focus of this project is integrating these STFs into a shoe sole and attaining the right balance between damping and rebound.

Fig. #1 Drop Tower Set-up

PROJECT OVERVIEW

The lifecycle of an athlete spans from their first competition to their ultimate retirement. During the lifecycle of an athlete, competitions present opportunities for showcasing an athlete's passion for their sport and competitive drive but, unfortunately, also injury. One cause of athletic injuries stems from vibrations and forces resulting from repetitive jumping and landing in sports like basketball and volleyball. In addition to technique and recovery, proper equipment, specifically footwear, plays a vital role in injury prevention and athletic performance. This presents the opportunity for an innovative shoe sole design to effectively reduce impact vibrations and forces.

Through the implementation of shear-thickening fluids (STFs) in shoe soles, the current project aims to mitigate impact vibrations and forces for increased athlete lifecycles and injury prevention. To fulfill these project goals, several simplified shoe sole heel designs have been developed, 3D printed, and injected with in-house STFs. Then, a series of viscosity and drop tests were performed to quantify the performance of each design.

The purpose of the project is to quantify the attenuation of impact vibrations and forces utilizing STFs in shoe soles and compare the performance of each shoe sole design to existing athletic shoes on the market.

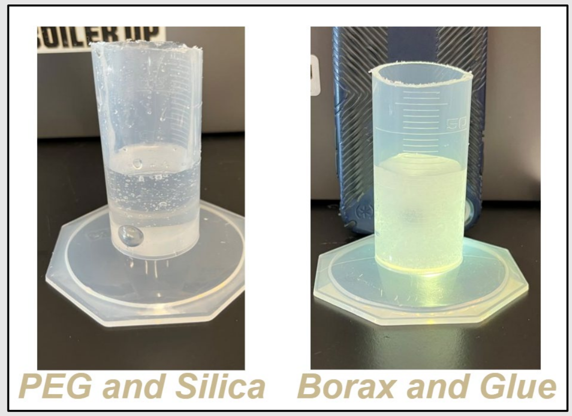


Fig. #2 Viscosity Ball Drop Experiment Set-up

PROJECT METHOD AND RESULTS

The project team created two STFs to be tested within the shoe sole designs. One was a 500 g cloudy solution comprised of 60% tap water, 23.5% PVA glue, and 16.5% borax detergent. The other was a 16 g clear solution consisting of 90% polyethylene glycol (PEG) and 10% silica. Each STF was stirred and rolled for one hour to ensure homogeneity. The STFs were then stored in sealed jars for two days to give sufficient time for residual mixing stresses to dissipate, properties to distribute uniformly, and to prevent any contamination. After this gestation period, each STF was placed into a graduated cylinder. A small steel ball was subsequentially dropped into the mixture, and the time it took for a ball to travel through the STF in its entirety was recorded. This experiment described can be seen in Figure 2.

1105 Endeavour Drive Suite 400, West Lafayette, IN 47906
Dr. Jan-Anders Mansson,
Executive Director
jmansson@purdue.edu
WWW.ENGINEERING.PURDUE.EDU/ENGR/EWRY

STF	Fall Time (s)	Resting Viscosity (Pa*s)
Borax and Glue	454.65	2034
PEG and Silica	6.57	32.204

$$\eta = \frac{2gr^2(\rho_2 - \rho_1)\left(1 - \frac{r}{R}\right)^{2.25}}{9v}$$

Variable	Description
g	Gravity
r	Ball radius
ρ_1	STF density
ρ_2	Ball density
R	STF radius
v	Falling time/distance

Fig. #3 Viscosity Experiment Results and Calculations

PROJECT METHODS AND RESULTS CONT.

Based on the governing equation for non-Newtonian fluid viscosity seen in Figure 3, the resting STF viscosities were calculated. This viscosity diversity was desirable for the project team as it will help to identify the influence, if any, of resting viscosity on STF damping. A process in which the viscosity should increase as a response to a substantial and sustained force of impact. To test this STF damping process, the STFs were injected into various shoe sole models that the team 3D printed. Each design was simplified as hollow, rounded rectangular prisms with dimensions of 100 x 70 x 35 mm. The dimensions were chosen to replicate the heel of a basketball shoe. As for the 3D printing parameters, the shoe was produced with a Raise3D Pro2 Plus out of a thermoplastic polyurethane (TPU) filament at a 20% infill. Each design took twelve hours to print and another eight hours of post-processing to dissolve the polyvinyl acetate (PVA) support material, which was necessary for the complex internal geometry of the designs. Due to time constraints, only three designs were created: hollow, triangle, and rectangle as seen in Figure 4.

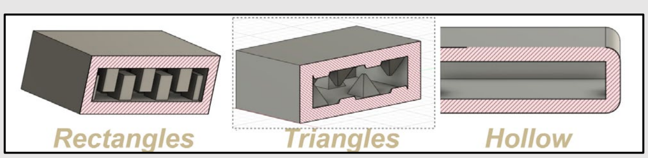


Fig. #4 Shoe Sole Simplified Designs

PROJECT METHODS AND RESULTS CONT.

Each design incorporated two small slots: one for STF injection and the other for air release. The filled models, and an unfilled control, were then placed under a drop tower, shown in Figure 1, that, upon release from 40.5 in., would strike the model with a 5 lb. cylindrical weight. From this drop test, the team measured rebound height, deformation time, and deformation distance to determine the energy recovery ratio and shear rate as seen in Figure 5. Unfortunately, the shear rate was unable to escape the linear region, so damping due to a shear thickening effect was likely minimal.

Design	STF	Drop Height (in)	Rebound Height (in)	Energy Recovery Ratio (%)
Hollow	Borax and glue	40.5	10.07	24.85
Triangles	PEG and silica	40.5	8.97	22.14
Rectangles	Borax and glue	40.5	8.50	20.99
Hollow	Unfilled	40.5	9.15	22.59

Design	STF	Deformation Height (in)	Impact Time (s)	Structure Distance (mm)	Shear Rate (s^{-1})
Triangles	PEG and slica	0.192	0.0378	6.69	38.54
Rectangles	Borax and glue	0.2	0.0361	5	56.27

Fig. #5 Drop Tower Experiment Results

CONCLUSIONS AND FUTURE WORK

Conclusions

- 3D printed physical shoe sole heel models with varying internal geometrical patterns out of TPU filament
- Established standard drop testing procedures and identified areas for testing improvements
- Calculated experimental shear rate and energy recovery for shoe sole models injected with STFs
- Obtained promising initial results indicating successful impact damping

Future Work

- Focus on combining rebound effect, or energy restitution, with impact damping effect
- 3D print and test full-size physical shoe soles for more realistic athletic performance testing

ABOUT RESEC

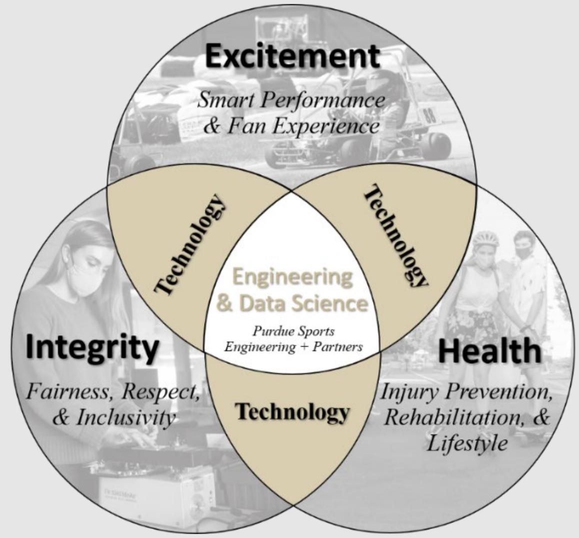
The Ray Ewry Sports Engineering Center (RESEC) was launched as a joint collaboration between Purdue College of Engineering and Purdue Intercollegiate Athletics, highlighting Purdue's reputation as the Cradle of Quarterbacks and Astronauts.

Sports have the power to unite, to teach, to challenge, and to initiate change, and those are our goals for RESEC. We are driven by our passion for sport and a deep understanding of the influence it has in shaping society. As technology continues to advance, there is enormous room for opportunity to rethink how athletes train, coaches coach, fans engage, and event organizers plan events. We collaborate closely with partners in athletics, industry, academia, and more to create the solutions that will help bring sports into the future, specifically in the three key research areas highlighted below.

Smart Performance & Fan Experience

Injury Reduction & Rehabilitation

Sports Integrity, Fairness, & Societal Integration



WHAT IS SPORTS ENGINEERING?

Sports engineering is a global, fast-paced, and multidisciplinary industry that brings people from different backgrounds, cultures, and experiences together. It is an industry that is heavily influenced by advances in other sectors as well as societal pressures and shifts, making working as a sports engineer very exciting. However, it also means being keenly aware of how these innovations and discoveries can be integrated and applied, especially as digitalization expands and what people – the athletes, fans, coaches, governing bodies – expect from sport evolves.

Engineering and data science are at the center of excitement, health and safety, and the integrity of sport, and by bringing a data-driven, human-centered approach to this industry, we can address the growing need and desire to increase participation and engagement of athletes and fans.

WHO IS RAY EWRY?

A Boilermaker track and field athlete, Ewry (1873-1937) won eight gold medals in three Olympic Games from 1900 to 1908. But his story is relatively unknown: at the age of five he became an orphan, and at seven he contracted polio and was confined to a wheelchair. Doctors had little hope he would be able to walk. Later nicknamed "The Human Frog," Ewry won gold in the standing long and high jumps and standing triple jump. By the end of the 1908 Games, Ewry had set a medal count record that lasted more than 100 years.

1105 Endeavour Drive Suite 400, West Lafayette, IN 47906

Dr. Jan-Anders Mansson, Executive Director
jmansson@purdue.edu

WWW.ENGINEERING.PURDUE.EDU/ENGR/EWRY