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Engineering a Better Pointe Shoe

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Abstract

Modern pointe shoes have exhibited little variation since their creation in the late 18th century. Despite all of the technology that has been developed since then, pointe shoes remain ephemeral, the primary materials being a specialized paste, compressed cardboard, paper, and satin. This brevity of life causes them to be expensive, can lead to injuries, and limits the dancer's ability. Although there are several modernized pointe shoe models, the oldest manufacturer still dominates the market. This project aims to create a better pointe shoe by simulating a more robust construction and exploring multiple materials for pointe shoe components.

The Problems

After polling 30 dancers from across the country, the following problems were identified as most imperitive

- **Longevity**
  Especially given the cost, pointe shoes have an incredibly short lifespan of 12-15 hours [5]. Some professionals will even go through multiple pairs in a performance [6].
- **Cost**
  Due to the volume of shoes that dancers go through per season and per year, a ballet company can spend about $780,000 in shoes alone [3]
- **Consistency**
  The dancers want to know that if they're spending significant amounts of money on their shoes that they're going to be wearable

Figure 1. Dead Shank [4] and Dead Box [1]

Von Mises Yield Criterion

The von Mises yield criterion is a value used to predict if a material, particularly ductile ones, will fail. This was the criterion used in the SolidWorks simulations.

$$\sigma_{VM} = \sqrt{\frac{1}{2}\left[(\sigma_1-\sigma_2)^2+(\sigma_2-\sigma_3)^2+(\sigma_3-\sigma_1)^2\right]}$$

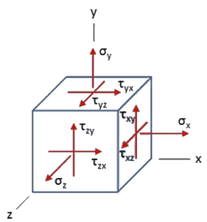

Figure 2. Stress Component Diagram

The Tested Materials

- Acrylonitrile Butadiene Styrene, ABS
- Polycarbonate, ABS-PC
- Nylon 6/10
- Polylactic Acid, PLA
- Polypropylene, PP

The SolidWorks Model

Measurements were taken from a new pointe shoe for the model. From these, each indiviual component (i.e. each layer of the shank, the box, and the outer cover) could be drawn in SolidWorks.

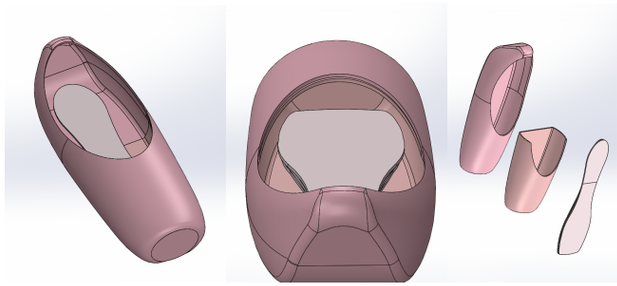

Figure 3. The final model.

The Simulations

In the SolidWorks model of the shank, there are three layers:

1. **Inner Leather Sole** To preserve the classic appearance of a pointe shoe, the top layer was assigned as leather
2. **Full Layer** Typically this would be compressed cardboard, but for our tests this is the layer we focused on changing
3. **Three-Quartered Layer** This layer is also usually compressed cardboard or sometimes wood, but we chose *Ultra High Molecular Weight Polyethylene* (UHMWPE) to reinforce the structure of the shank in our design since it has excellent mechanical properties for this application.

Bending the Shank

1. The bottom edge of the shank and a portion of the three quartered layer was fixed while the load was applied to the heel to mimic passing through demi pointe
2. A load of 511.2 MPa (a 115lb dancer's weight force) was applied to the shank
3. The load was applied to the assmebled shank for *each* material
4. The von Mises stresses were recorded for each test

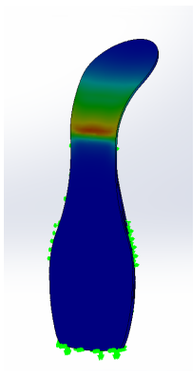

Figure 4. Deformed ABS Test

Analysis

All five of the materials were able to withstand the higher load, even without extra reinforcements from the rest of the shoe.

For now, we use qualitative analysis based on material properties to eliminate candidates given that they all withstood the simulations.

Material	Advantages	Disadvantages	Filament Cost [$/kg]
ABS	High flexibility and impact resistance	Flammable and soluble in some organic solvents	20-30
ABS-PC	Low water absorption high impact strength	More expensive	75-95
Nylon	Excellent impact resistance	High water absorption low strength	80-110
PLA	High strength and rigidity	Poor durability, brittle	20-30
PP	Excellent fatigue strength, inexpensive	Poor resistance to UV light	20-30

Table 1. Material Comparison Chart

Conclusions

Best Candidates

ABS
The lesser properties aren't particularly relevant to this application and ABS is inexpensive as well as easy to 3D print.

PP
Like ABS, the disadvantages aren't relevant to the application. The excellent fatigue life is highly appealing and PP is fairly inexpensive.

Next Steps

Fatigue Simulations
Verify that these materials are truly the best candidates by conducting fatigue tests and recording life cycle data.

Test Prototypes
Once the prototypes are printed, they should be tested by a real dancer in the shell of a normal pointe shoe with the shank removed.

3D Print Prototypes
Once the best materials are confidently identified, prototypes will be 3D printed using the STL files from the SolidWorks model

Box and Complete Model
Further simulations should be done on the box and the assembled shoe to determine a maximum load and fatigue life given extreme external loads.

References

[1] Jonathan Boneck. *Dead Pointe Shoe Box.*

[2] William D. Callister and David G. Rethwisch. *Materials science and engineering: an introduction.* Wiley, 10 edition, 2018.

[3] Margaret Fuhrer. The secrets of new york city ballet's pointe shoe room, Feb 2020.

[4] Amber Hunt. *Dead shank pointe shoe.* Mar 2015.

[5] Russian Pointe. *Pointe Shoe Longevity.*

[6] Pittsburgh Ballet Theatre. *The Point of Pointe Shoes.*

Acknowledgements

USM Lasers and Materials Engineering Research Group