Adaptive Cycling Shoes

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Biomedical Engineering

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Introduction:

The Adaptive Cycling Shoes research team developed a pair of shoes and bicycle pedals to allow for a former Army Captain to compete in road cycling events after sustaining lower limb injuries. The design plan to promote pain-free cycling included HOKA running shoe bases with innovative BOA fit tightening mechanisms, water and chemical-proofing, formulated orthotics from professional-grade materials (PG), and transplanted cycling shoe soles which incorporated ferrous metal plates to permit interface with neodymium-magnet-containing pedals and 3D-printed componentry. Testing protocols were developed and utilized to ensure pedals and shoes met industry standards.

Material Selection and Validation:

The material selection process for the Adaptive Cycling Shoes team included four concept selection grids for determining correct materials and design for the cycling shoes, pedals, 3D-printing filament for the magnet housing units (Table 1), and for low-cost orthotic formulation (Note: more concepts were included in the grid however only the highest scoring and two comparisons are shown). The highest scoring designs are shown below (Fig. 1-3). The low-cost orthotic concept selection grid was created prior to being provided with professional-grade orthotic materials (Table 2). A weight drop test was completed which indicated that the professional-grade material had less deformation under stress and, therefore, should be incorporated into the final product instead of low-cost.

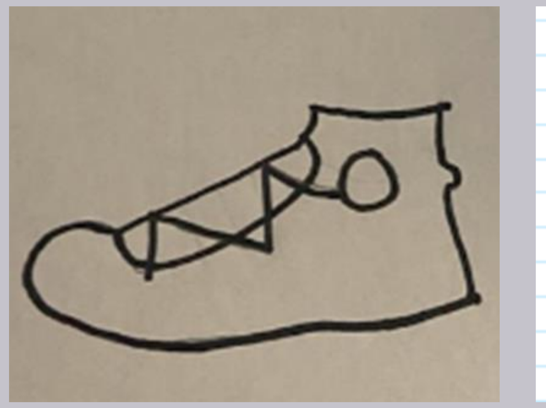

Fig. 1. BOA lacing system concept

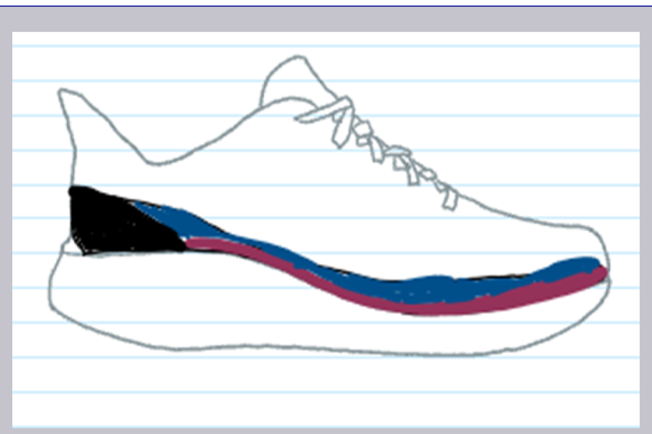

Fig. 2. HOKA with integrated orthotic concept

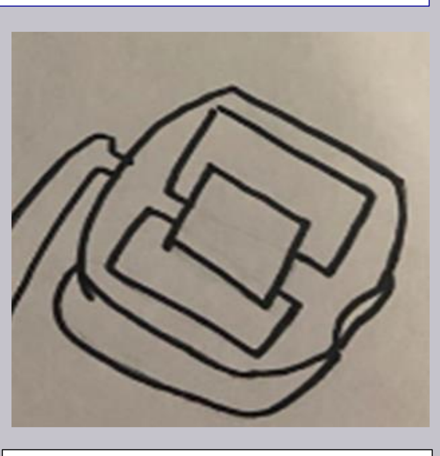

Fig. 3. 3D-printed pedal with neodymium magnet concept

Type of Filament	Tensile Push Strength	Longevity	Tensile Strain at Break	Heat Deflection	Flexural Strength	Density	Total
Onyx	-	+	-	+	+	+	+2
Nylon-X	+	-	+	-	-	-	-2

Table 1. *Filament Concept Selection Grid.* Green indicates filament chosen for final design.

Orthotic Material	Shock Absorption	Cushioning	Irritation Prevention	Ability to be molded	Durability	Similarity to professional materials	Total
Cork-Foam-Batting	0	5	4	3	-4	-3	5
Cork-Foam-Tool Box Padding	1	5	4	3	4	3	20
Cork-Batting	-1	-5	4	-3	-4	-3	-12

Table 2. *Low-Cost Orthotic Concept Selection Grid.* Green indicates orthotic chosen for testing and comparison to professional-grade materials.

Design Process:

The research team decided to segment the device design process down into three major sections: the pedal, orthotic, and shoe. In terms of the pedal, it went through three major revision stages (Rev. 1 and Rev. 3 designs are shown in Figures 4 and 5 respectively). The original plan was to 3D-print entire pedals, however there were concerns about longevity of the device. Therefore, it was determined integral to adjust the design to existing pedals with attached 3D-printed housing units for the magnets (which are then secured into the pedals with set screws). In terms of the orthotic generation, a Bio-Foam Impression box was utilized to obtain an imprint of Mr. Osborne's right foot (Fig. 6), followed by using the imprint to create a plaster mold (Fig. 7). From this mold, a professional-grade orthotic was created through softening materials in ovens, utilizing industry adhesives, and activating material shaping around the mold via a vacuum press (Fig. 8). For the shoes, the HOKA-base (shown in Fig. 9) was utilized and designed with a BOA fit system integrated into the lacing and underwent cycling shoe sole transplants (shown in Fig. 10).

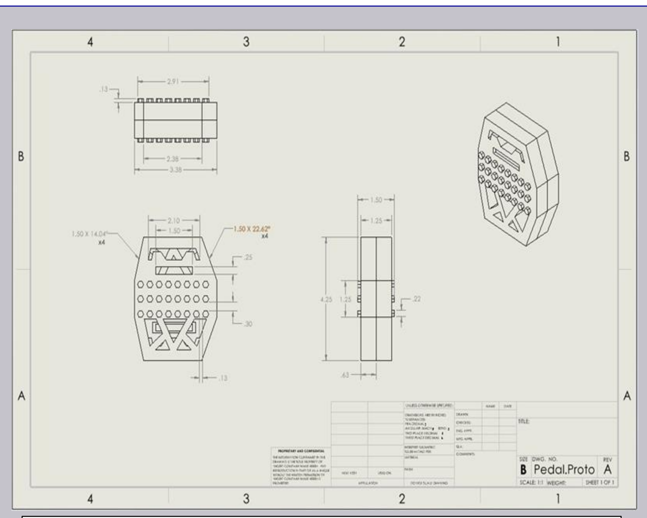

Fig. 4. Rev. 1 Pedal Design

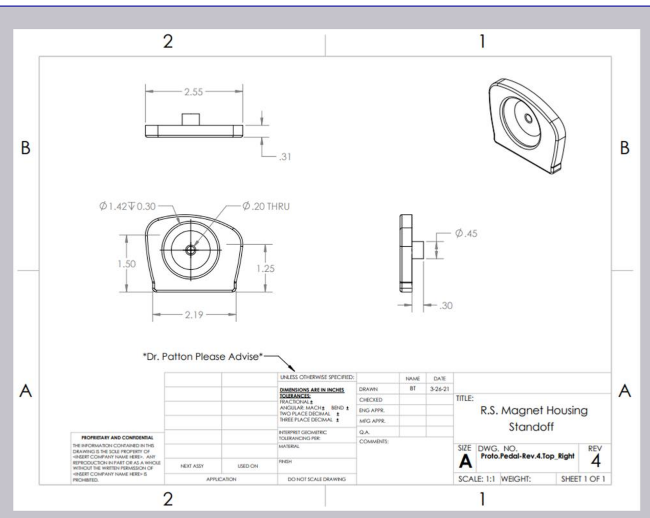

Fig. 5. Rev. 3 Pedal Design

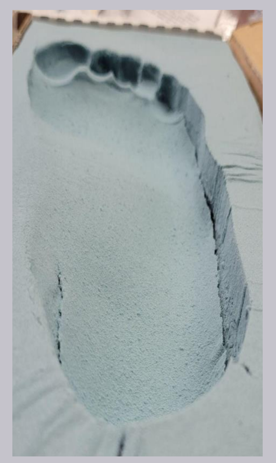

Fig. 6. Biofoam imprint of right foot

Fig. 7. Plaster mold of right foot

Fig. 8. Final Professional-Grade Orthotic

Fig. 9. HOKA base

Fig. 10. Cycling shoe

Final Device:

The final device (shown in Fig. 11) includes HOKA-bases with integrated BOA-fit lacing systems, treatment with waterproofing spray, transplanted cycling shoe soles, and metal plates for integration with the neodymium magnets fastened into 3D-printed housing units. (Fig. 12 shows the housing units set into existing pedals.) Additionally, a custom professional-grade orthotic for the customer's right foot was formulated separately from the shoes.

Fig. 11. Final designed cycling shoe

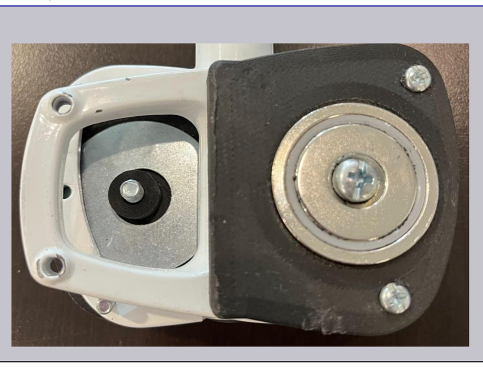

Fig. 12. Final designed pedal

Functional Validation Testing:

In order to validate each portion of the design, multiple tests were completed. In terms of the orthotic, a Weight Drop Test analyzed impact attenuation for material options. Data analysis of final results concluded specimens were statistically different. Bar graph displays overall degradation quantity, with preference in least thickness change. Test results concluded professional-grade (PG) materials were preferred over low-cost (LC) materials. Specimen visually confirmed this with LC having permanent deformation while PG had high elasticity performance. For the shoes, in order to test environmental conditions, a water test was completed. The testing involved applying water to a control, samples treated with Guardsman Fabric Defence Spray, and samples treated with Kiwi Protect-All Waterproofing Spray. The results indicated that the Guardsman treatment allowed significantly less water to penetrate and was therefore utilized to treat the shoes. A corrosion test was completed to test an extreme environmental condition of acid rain through exposing two metal plates to 6 M HCL. Results are shown below and indicate that the black plate was less susceptible to weight loss and decreases in thickness than the Magped plate, and therefore should be attached to the final shoes. Tensile testing was completed to determine the maximum tensile strength of the Onyx printed filaments. Filaments were printed at 25 °C and 35 °C. The 35 °C printed dog bones resulted in the highest average tensile strength by 0.8 MPa. A pass-fail load test was completed, involving a team member cycling with prototype shoes and pedals. A pass result was recorded with neither shoe nor pedal failing.

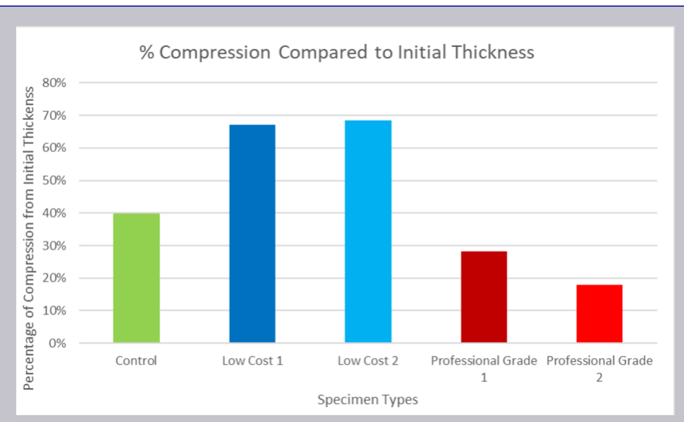

Fig. 13. Weight Drop Test Results

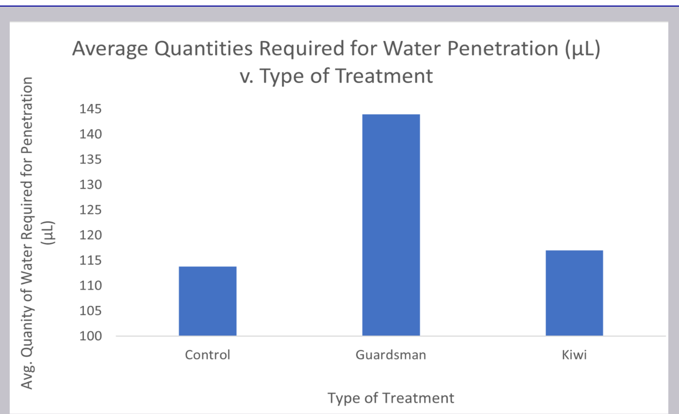

Fig. 14. Water Penetration Test Results

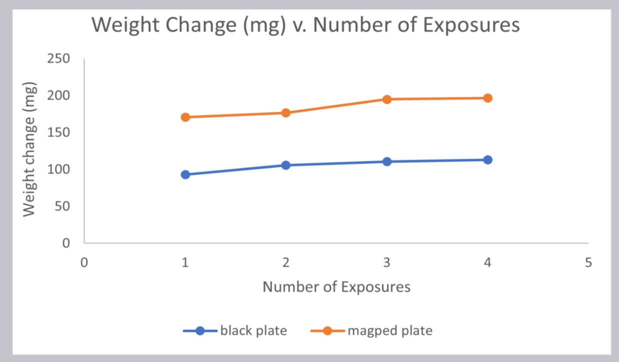

Fig. 15. Corrosion Test Results

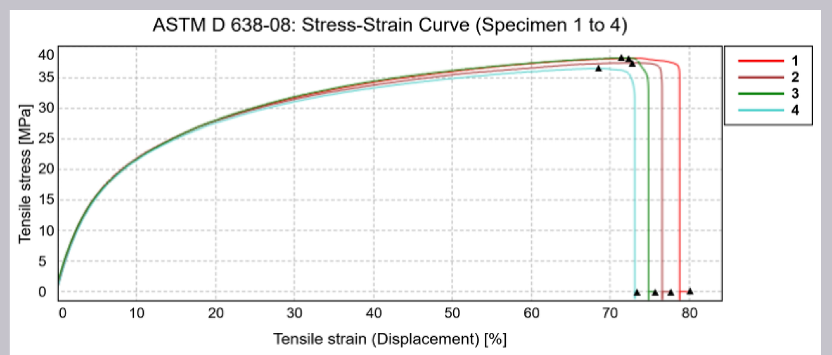

Fig. 16. Tensile Test Results

Recommendations for Future Work:

After a test ride, the customer noted risk of irritation to his fifth metatarsal. Shoe stretching or adding internal padding were considered, but not recommended by professionals. Best solutions would be either removing material from the internal surface of the shoe or reducing tension from the installed BOA fit system. Additionally, the customer requested to have higher connectivity between the shoes and pedals (primarily for power strokes during uphill riding), therefore the team will be researching higher strength plates to screw into the shoe soles.

Acknowledgements:

The Adaptive Cycling Shoe Team would like to recognize Dr. John Patton, Mitch Petersen & the Prevail Prosthetics and Orthotics staff, Neil Buehler, Paul Cauley from Hanger Clinic, Keith Didion, the staff at Chuck's Shoe Repair, and Trine University Biomedical Engineering Department for being integral factors in the success of this project.