Materials Selection/Injection Molding Tooling Design for an Advanced Foot Orthotic – Phase 3

NDSU NORTH DAKOTA STATE UNIVERSITY

KINGETICS RISE ABOVE

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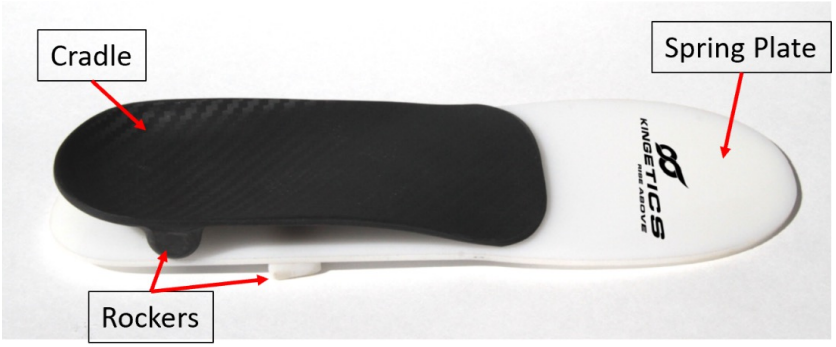
Mentor: Dr. Ulven

Sponsor: Dr. King from Kingetics, LLC

What is Kingetics, LLC?

- Owner/Founder: Dr. Steven King

- Advanced Foot Orthotic



Photos from https://www.kingetics.com/

Mechanics of the Product

Video from https://www.kingetics.com/

Past Semester's Work

- Phase 1 – Gurney Construction

- Phase 2 – Mechanics Testing

Phase III: Objectives

Goals:

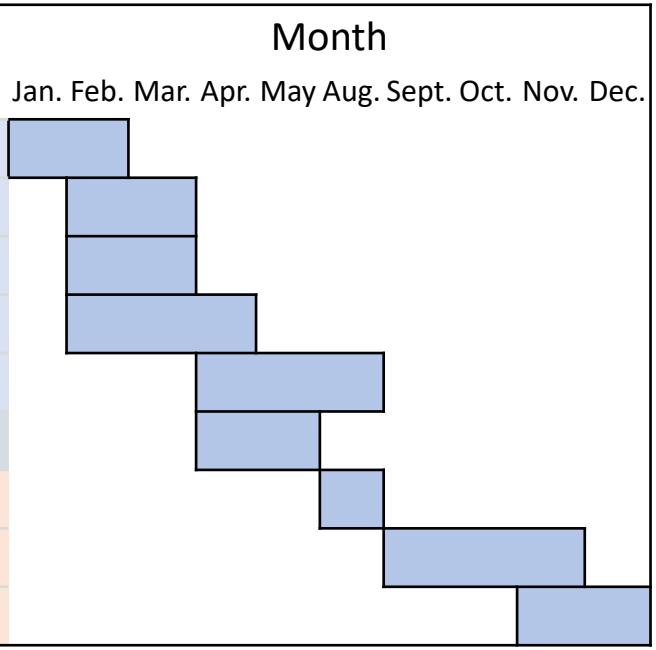
- Optimize Cradle
  - Design
  - Materials Selection
- Create a mold for injection molding
- Machine Prototypes and Run Tests

Constraints:

- One Shoe Size
- Each component should be a separate mold
- Spring Plate = 1 Piece
- Consider dynamic loading

Phase III: Gantt Chart

Tasks:	Completed	Start	Finish
A. Planning and Organizing	100%	1/8/22	2/25/22
B. Resources and Budgeting	100%	2/12/22	3/12/22
C. Materials Research and Selection	100%	2/21/22	3/25/22
D. Cradle and Spring Plate Design	100%	2/28/22	4/8/22
E. Mold Design	25%	4/4/22	9/15/22
F. Spring Semester Presentation	100%	4/25/22	5/6/22
G. Revised Planning and Budget	0%	9/13/22	9/20/22
H. Prototype Testing	0%	9/20/22	11/22/22
I. Fall Presentations	0%	11/22/22	12/9/22



Risk Plan

Weather

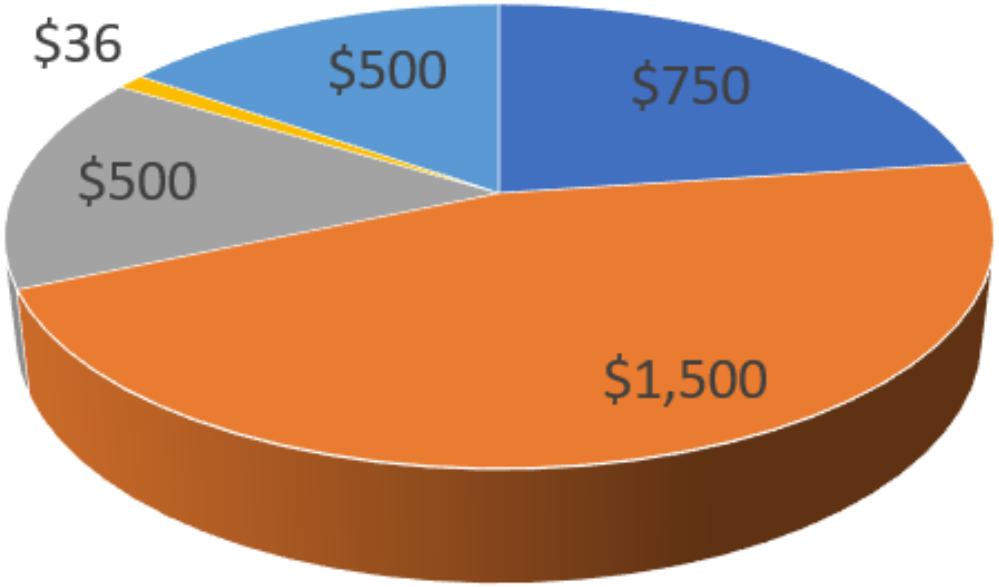
COVID

Machining Time

Supply Chain Delays

Budget

Total Budget: $3,286



Bill of Materials

https://img.alicdn.com/imgextra/i3/6000000000292/O1CN01HSkyHN1E1mGpg7Brn_!!6000000000292-0-tbvideo.jpg

https://themetalsfactory.com/product/aluminium-products/blocks/6061-aluminium-blocks/

Composite Pellets

Mold Machining

- Aluminum Blocks
- End Mills

Poster Board

https://epictool.ca/end-mills/

Materials Selection Criteria

- Current Material: Delrin (polyoxymethylene)
  - Match flexibility and density
  - Improve strength and lifetime
    - Delrin has low endurance/high creep
- Selection Criteria:
  - Injection moldable, thermoplastic
  - Carbon-fiber filler
  - Flexural Modulus: ~450 ksi
  - Compressive Yield: >10 ksi
  - Density: <0.054 lb/in^3
  - Minimize moisture absorption
  - Minimize cost

Granta EDUPack

- Granta EDUpack
  - Used to analyze different materials
  - Properties can easily be compared and filtered
  - Rough price estimates are also listed

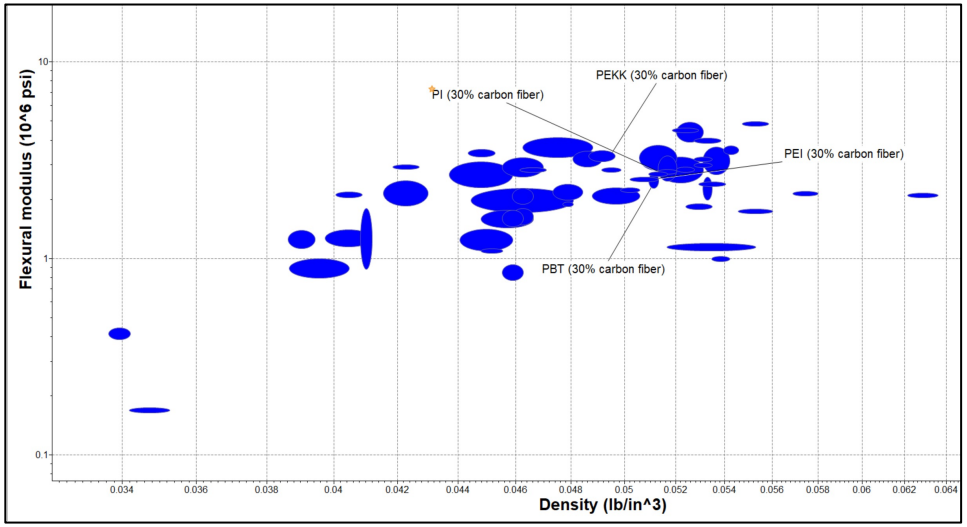
Composition overview

Compositional summary

Homopolymer of (CH2-O)n (from formaldehyde or trioxane)

Material family		Plastic (thermoplastic, semi-crystalline)			
Base material		POM (Polyoxymethylene / acetal homopolymer)			
Polymer code		POM			
Composition detail (polymers and natural materials)					
Polymer		100			%
Price					
Price		* 0.685	-	0.989	USD/lb
Price per unit volume		* 60.3	-	88.3	USD/ft^3
Physical properties					
Density		0.0509	-	0.0517	lb/in^3
Mechanical properties					
Young's modulus		0.4	-	0.521	10^6 psi
Young's modulus with temperature		0.474	-	0.474	10^6 psi

Parameters: Temperature = 73.4°F



Materials: Screening

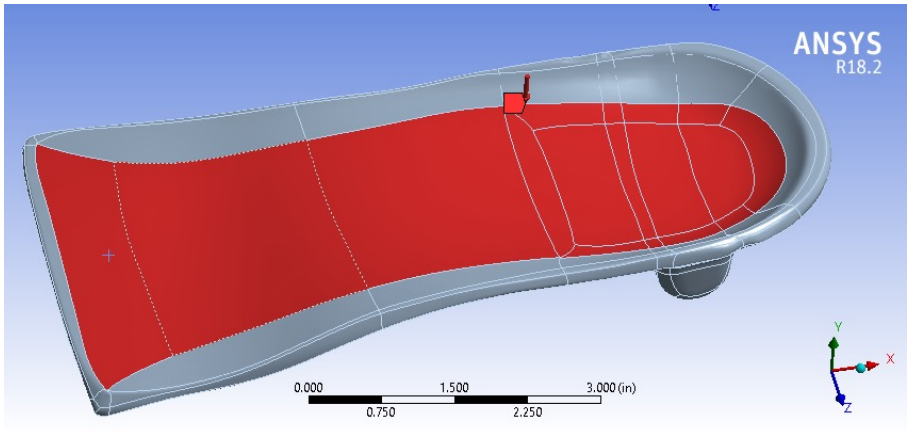
	Modulus	Compressive Yield	Density	Cost	Moldability	Fatigue Limit	Moisture Absorption	Total
POM - Acetal	0	0	0	0	0	+	0	1
POM - 30%C	+	+	0	+	0	0	+	4
PI - 30%C	+	+	0	0	-	+	+	3
PLA - 30%G	+	+	0	+	0	0	0	3
PEI-PCE - 30%G	+	+	0	+	+	0	+	5
PEI - 30%C	+	+	+	-	0	+	+	4
PCT - 40%G	+	+	0	+	+	+	+	6
PLA - 30%N	0	+	+	-	+	+	0	3
PP - 20%C	0	+	+	0	0	+	+	4

FEA - Overview

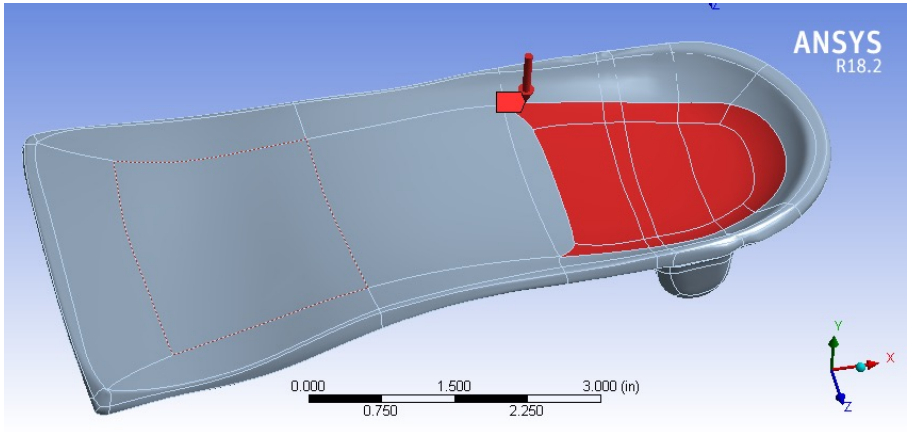
- Goals:
  - Evaluate remaining material candidates
  - Verify feasibility of design modifications
- Methodology:
  - Static structural analysis
  - 800-lb applied impact force
  - 3 loading cases for each material

FEA - Loading

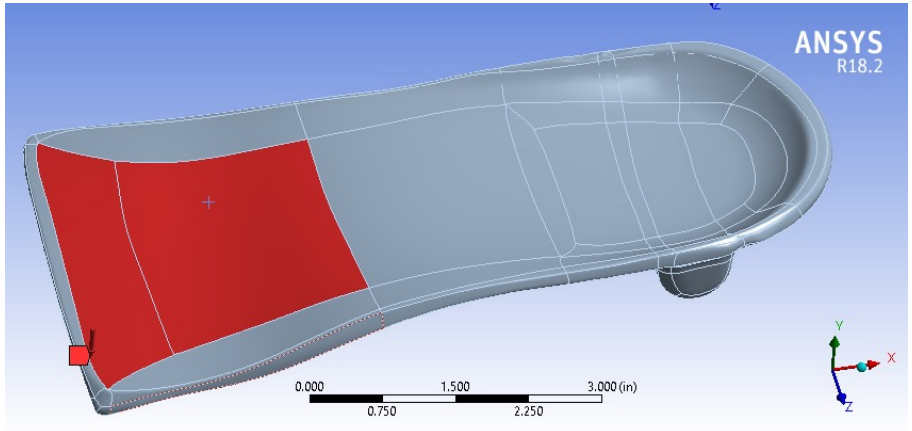
Loading cases:



Full Foot Contact: 44 psi



Heel Contact: 164 psi



Toe Contact: 104 psi

FEA - Results

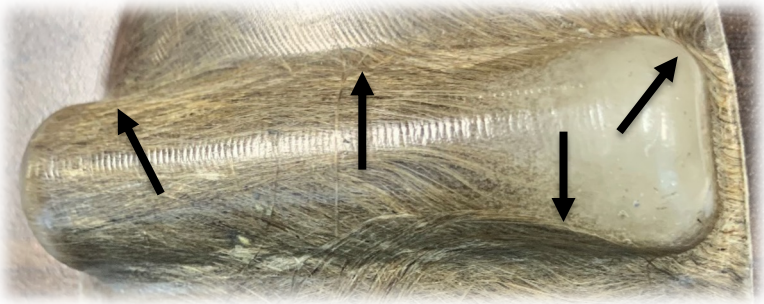
	Heel Contact		Full Foot Contact		Toe Contact	
	Factor of Safety	Deflection	Factor of Safety	Deflection	Factor of Safety	Deflection
PEI – 30% carbon fiber	5.39	0.010 in	5.14	0.060 in	4.46	0.101 in
POM – 30% carbon fiber	1.33	0.028 in	1.27	0.122 in	1.11	0.203 in
PP – 20% carbon fiber	1.38	0.033 in	1.59	0.141 in	1.14	0.335 in

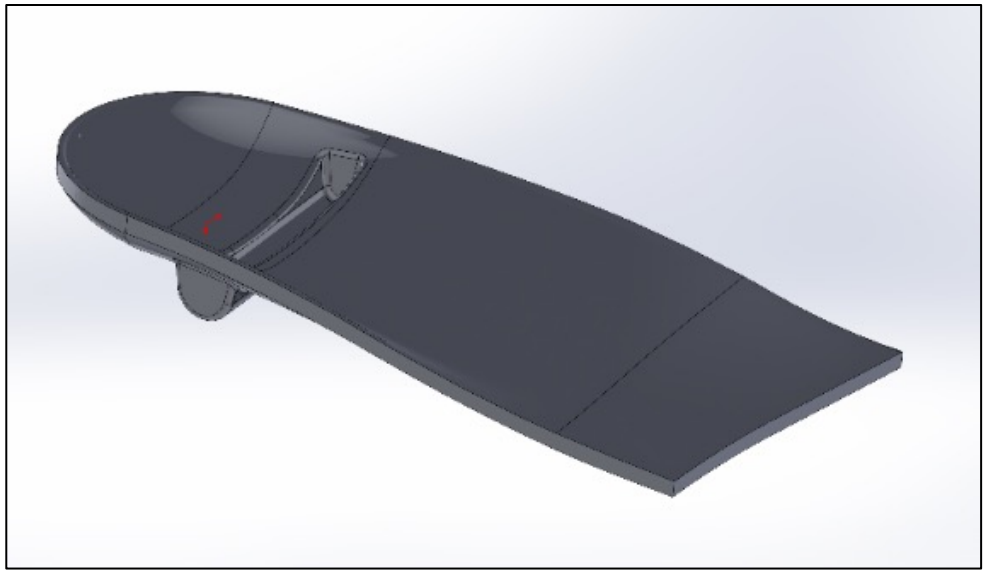
Materials – Decision Matrix

Criteria	Weight	PEI – 30% Carbon Fiber		POM – 30% Carbon Fiber		PP – 20% Carbon Fiber	
Factor of Safety	25%	5	1.25	3	0.75	4	1.00
Deflection	20%	5	1.00	3	0.60	4	0.80
Density	20%	3	0.60	3	0.60	5	1.00
Moldability	15%	2	0.30	4	0.60	3	0.45
Cost	15%	1	0.15	3	0.45	5	0.75
Moisture Absorption	5%	3	0.15	3	0.15	5	0.25
Total		3.45		3.15		4.25	

Design Decisions

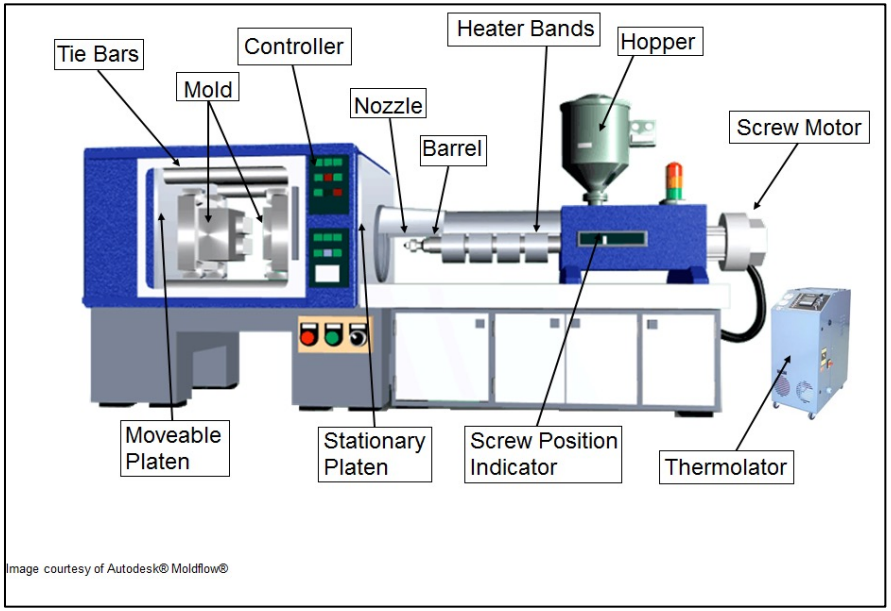
- Size and Surface Area: 32 in^2 max
  - Uniform Thickness Concerns
  - Consistent Round Dimensions
    - Addition of Ribs





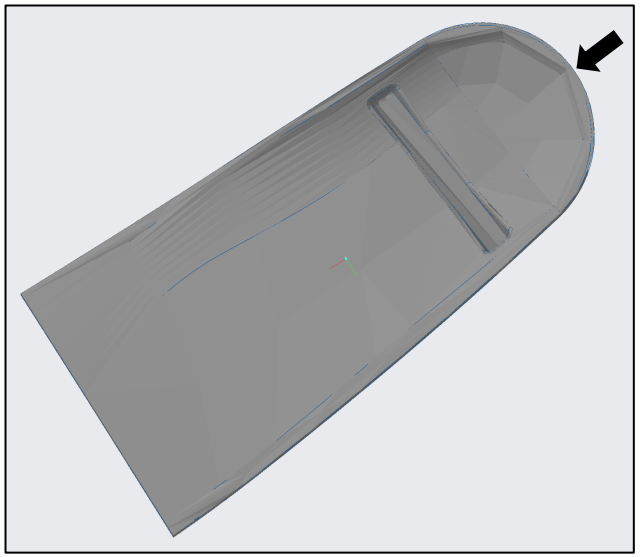
Injection Mold Designs

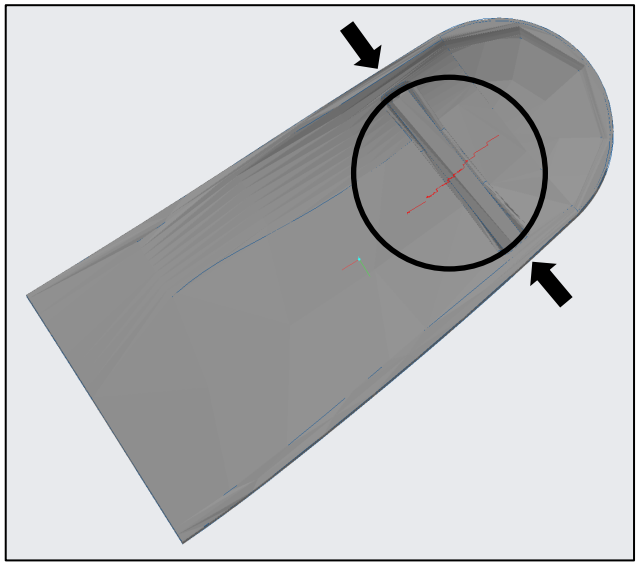
- Injection Molding Stage (Next Semester)
  - Planning on only molding the right-foot cradle
  - Mold will be able to produce one cradle per cycle
  - NDSU is helping with the molding process



Injection Mold Design

- Location of Gates
  - Important for proper and aligned mold flow
  - Improper mold flow leads to knit lines and other issues
- Ejector Pin Location
  - If possible, on back of part





Future Plans

- Wrap up design modifications
- Verify material performance in ANSYS with revised model
- Perform mold flow analysis
- Work with Rob Sailer to design and machine a prototype mold
- Produce and test prototype parts

Acknowledgements

- NDSU ME Department
  - Rob Sailer
- Rocket Composites
  - Paul Hewitt
- RTP Company
  - Jacob Kafer
  - Chris Diebel

Questions?