Department of Physical Medicine and Rehabilitation, Northwestern University Prosthetics-Orthotics Center

Tensile and Coefficient of Friction Testing of Textured Socket Specimens

Julia Quinlan[1], Vasanth Subramanian[1], Jessica Yohay[1], Gila Baer[1], Brad Poziembo[2] and Stefania Fatone[1]

[1]Northwestern University Prosthetics-Orthotics Center and [2]Prosthetic Design Inc.

Introduction

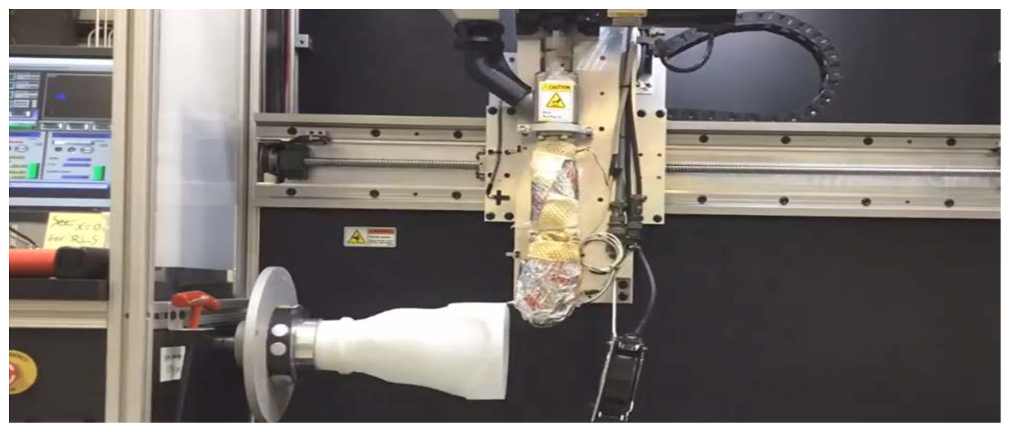
3D printing with fused deposition modelling (FDM) [1] results in objects with some texturing due to the deposition of materials layer-by-layer. However, the effect of socket texturing on socket suspension, rotation, fit, and comfort remains unknown. Textured prosthetic sockets may improve suspension by increasing the **coefficient of sliding friction (COF)** between the socket and liner-clad residual limb when compared to a smooth socket of the same material. However, printing different textures into the socket wall may influence bonding strength between layers, reducing **ultimate tensile strength (UTS)**.

Aim

To evaluate the effect of texture on the tensile strength of 3D printed socket samples and friction between socket sample/liner/sock using standardized tests.

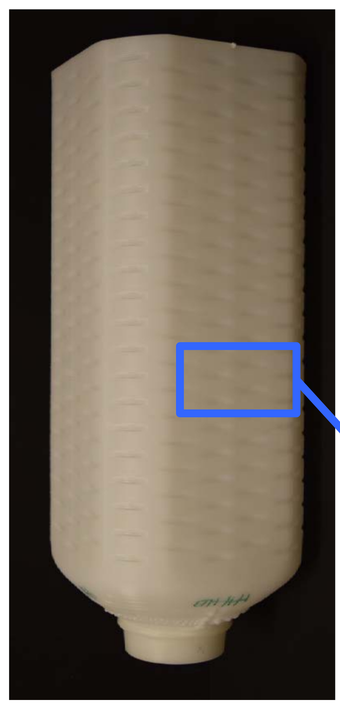
Hypothesis

We hypothesized that texture of polypropylene copolymer socket specimens would vary the UTS of the material. We also hypothesized that texture of polypropylene copolymer socket specimens would vary the COF of the material. Significance set at p=0.05 for both hypotheses.

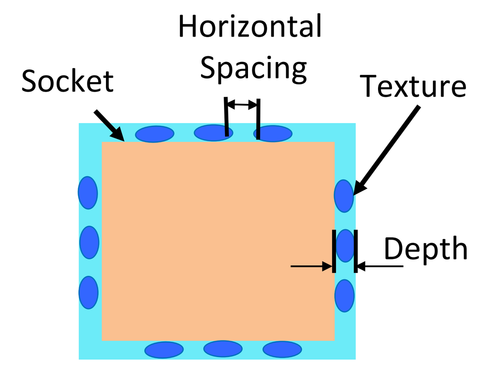


Original SQUIRT-Shape socket fabrication

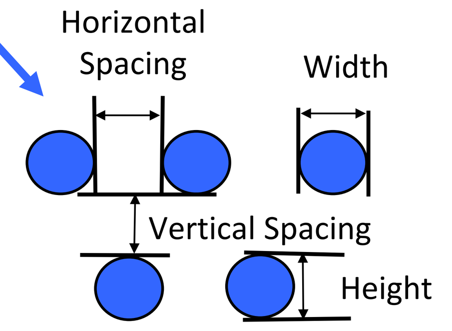
Textured socket Transtibial shape



Textured socket Rectangular shape



Cross-sectional view of socket



Methods and Results

Sockets

A selection of different texture patterns were programmed and 3D printed using the SQUIRT-Shape System [1]. A smooth thermoformed socket and a SQUIRT-Shape socket with original texturing consisting of horizontal striations approximately 1.2 mm in depth were used as controls.

Textured Samples	Densely distributed More aggressive (HD)	Lightly distributed More subtle (LS)
Horizontal line		
Vertical line		
Hemisphere		
Half-hemisphere		
Horizontal rectangle		
Vertical rectangle		
Checkerboard		

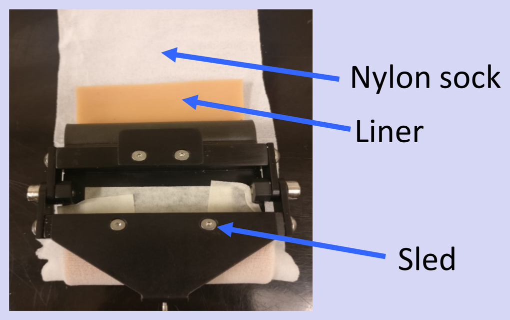
Reference Samples

Test	Description
Tensile COF	Smooth Raw Sheet (6mm thick) of Polypropylene Copolymer
Tensile only	Smooth Thermoformed rectangular socket made from 12 mm thick sheet of Polypropylene Copolymer
Tensile COF	Original SQUIRT-Shape Socket

Testing Protocol

Tensile testing Five dumbbell specimens per texture were measured using caliper, mounted to the Instron, preloaded to remove unwanted compression, and tested to failure. Rate of tensile loading was set at 5 mm/min per the ASTM D638 standard [2] and load was measured using a tension/compression load cell (1000 lb, MTS, Eden Prairie, MN).

COF testing Five COF specimens per texture were secured to the COF table and a calibrated sled wrapped in a piece of liner and nylon sock was dragged across the textured surface. Friction forces were collected with a tension/compression load cell (LRF400, Futek, 2.2 lb, Irvine, CA). The drive speed of the apparatus was set to 180 mm/min per the ASTM D1894 standard [3].



Top of the sled

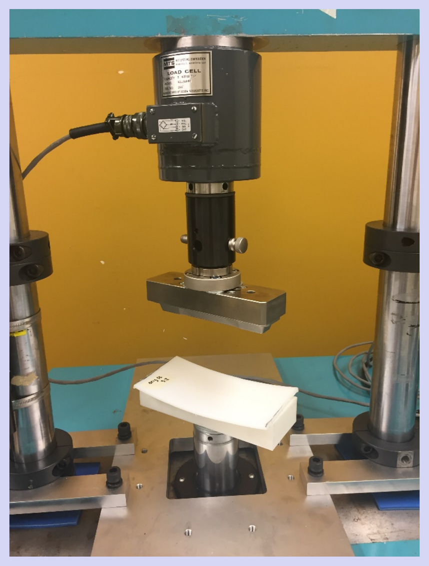
Bottom of the sled

Data analysis

UTS and static and kinetic COF were compared to reference samples that included a smooth sheet of the same polypropylene copolymer. UTS was assessed using a one-way ANOVA, while COF was assessed using a one-way MANOVA.

Specimen Fabrication

To obtain samples necessary for standardized testing of UTS and COF, we printed rectangular sockets with flat sides. The flat sides were then cut to obtain flat samples of different textures: **A) dumbbells** for tensile testing and **B) rectangular samples** for COF testing. Dumbbell preparation utilized a cutting die (Universal Grip LLC.) attached to a uniaxial hydraulic material testing system (Instron, Norwood, MA) to stamp out specimens with ASTM D638 Type I dimensions.



Stamping out dumbbells with cutting die

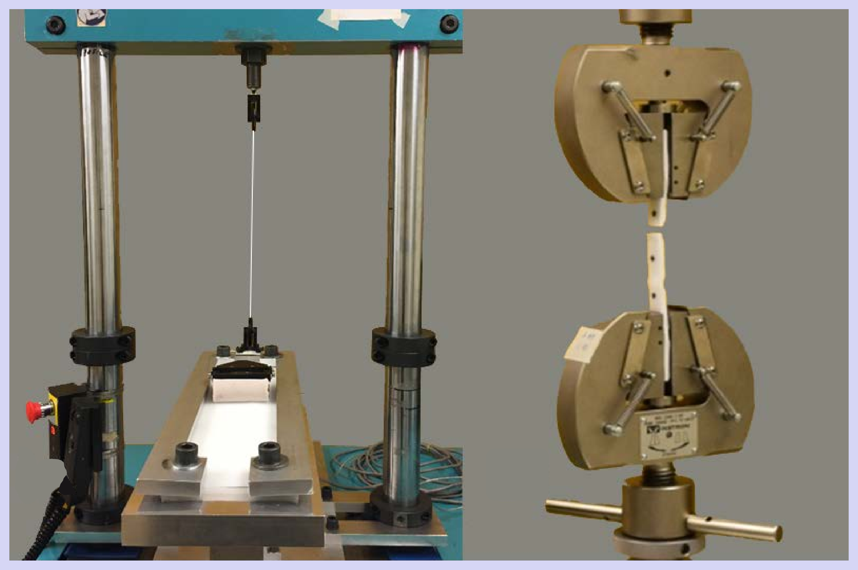
Dumbbells

Textured COF specimen

Mounting holes

Apparatus

Testing utilized a uniaxial hydraulic material testing system (Instron, Norwood, MA). For tensile testing, dumbbells were secured to the Instron using action wedge grips. For COF testing, specimens were secured to a custom COF testing frame.

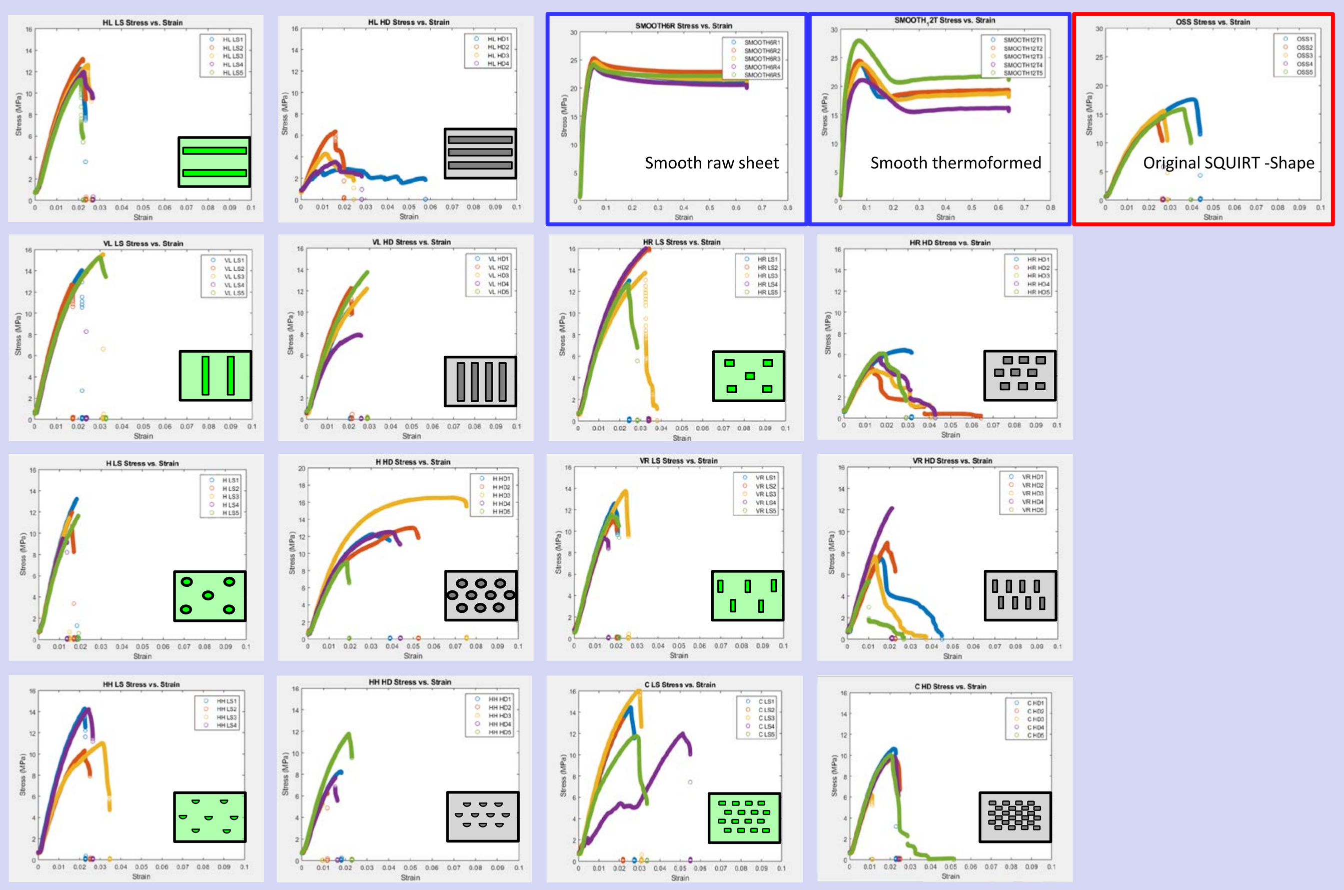


COF (left) and tensile testing (right) set up

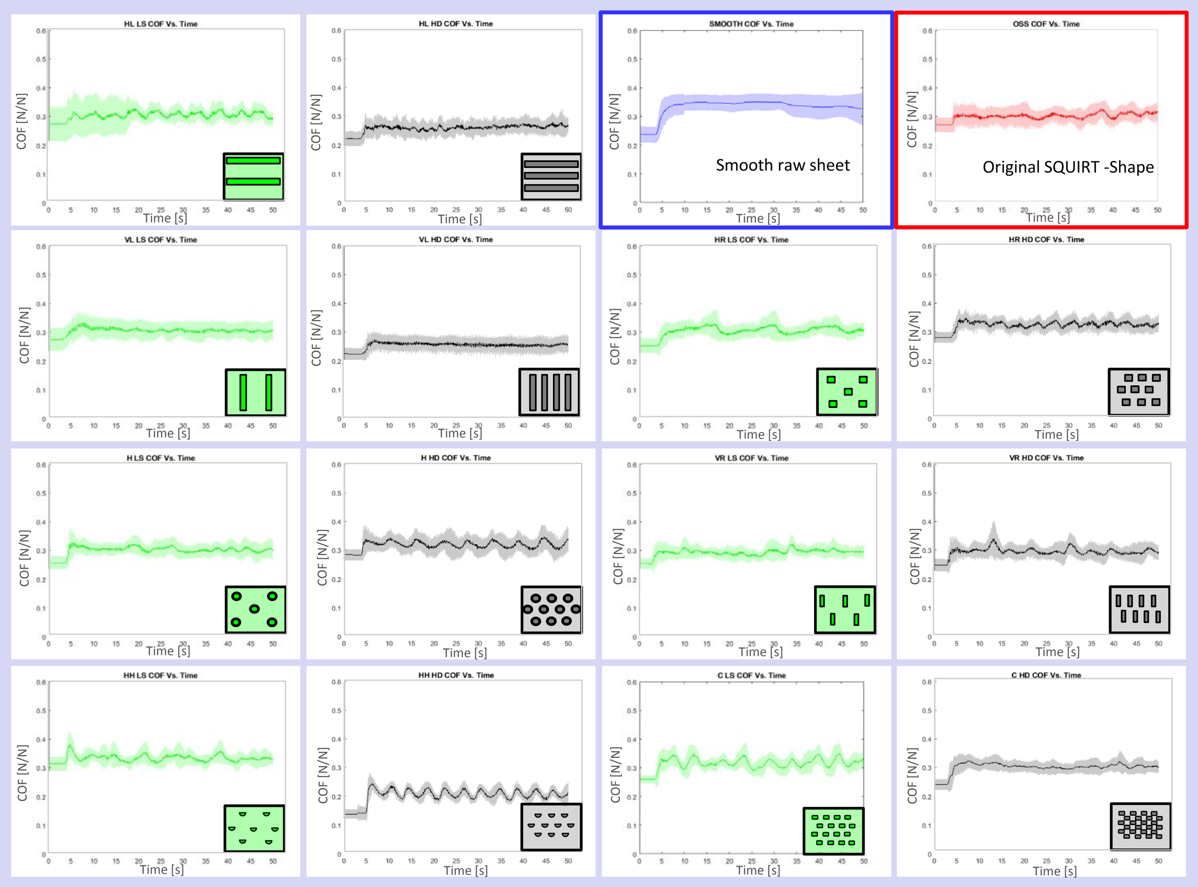
Results

There was a significant difference in UTS (p<0.0005) based on material texture with all textured samples being significantly weaker than the smooth reference samples (p<0.05). There was a significant difference in COF (p<0.0005) based on material texture, with both static (p<0.000) and kinetic COF (p<0.0005) being significantly different. While some textured samples had a larger static COF than the smooth reference sample, all but one textured sample had a lower kinetic COF.

Socket Sample	Ultimate Tensile Strength [MPa]	Static COF [N/N]	Kinetic COF [N/N]
Smooth Raw Sheet	24.48	0.352	0.341
Smooth Thermoformed	24.38	-	-
Original SQUIRT-Shape	15.46	0.363	0.304
14 Textured Samples	3.97 - 14.32	0.271 - 0.422	0.208 – 0.332



UTS Results



COF Results

Discussion

Tensile testing revealed a wide range of material strengths that depended on the distribution density of texturing as well as on the type of texture pattern. COF testing demonstrated that different textures influence friction properties between the socket, liner and nylon sock, and can be increased compared to the original SQUIRT-Shape socket.

Conclusions

These results provide an initial understanding of the effect of texturing on material properties, but further cyclic and static failure testing and test set-ups that mimic real-world socket conditions are needed.

References

[1] Rovick J. Automated Fabrication of Sockets for Artificial Limbs. PhD Dissertation, Northwestern University, 1993.
[2] ASTM D638–14: Standard Test Method for Tensile Properties of Plastics.
[3] ASTM D1894–14: Standard Test Method for Static and Kinetic Coefficients of Friction of Plastic Film and Sheeting.

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