Compliant robotic finger for optical probe positioning

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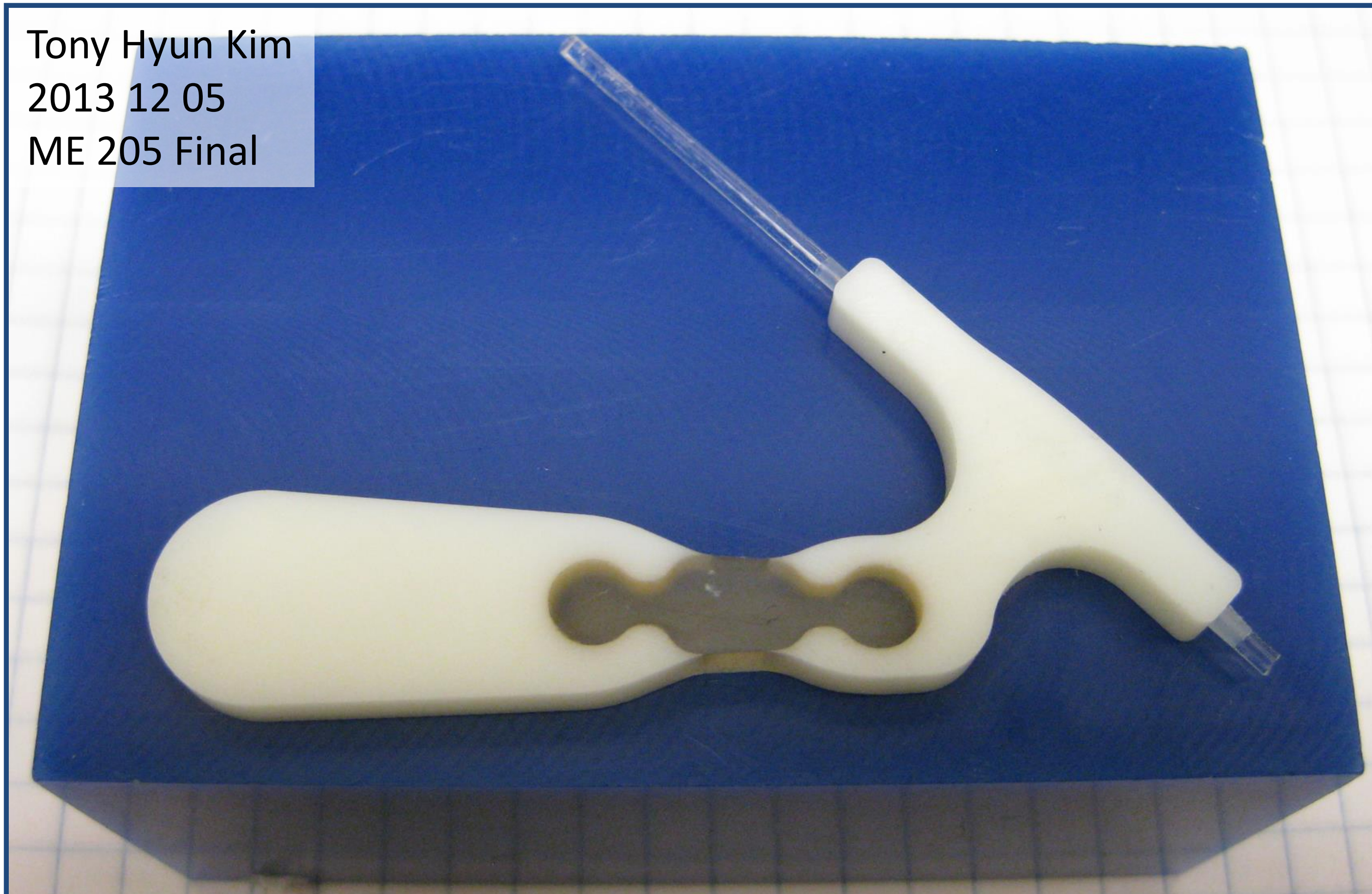
ME 205 Final



Project motivation

As part of my PhD work, I am involved in the R&D of optical probes for use in neuroscience / biomedical research. The diameter of each probe (tip) is 1~2 mm, and multiple probes need to operate in a workspace of ~(10 mm)^3. Given these operating requirements, it is likely that probes will collide with one another, leading to inevitable device damage and failure over time…

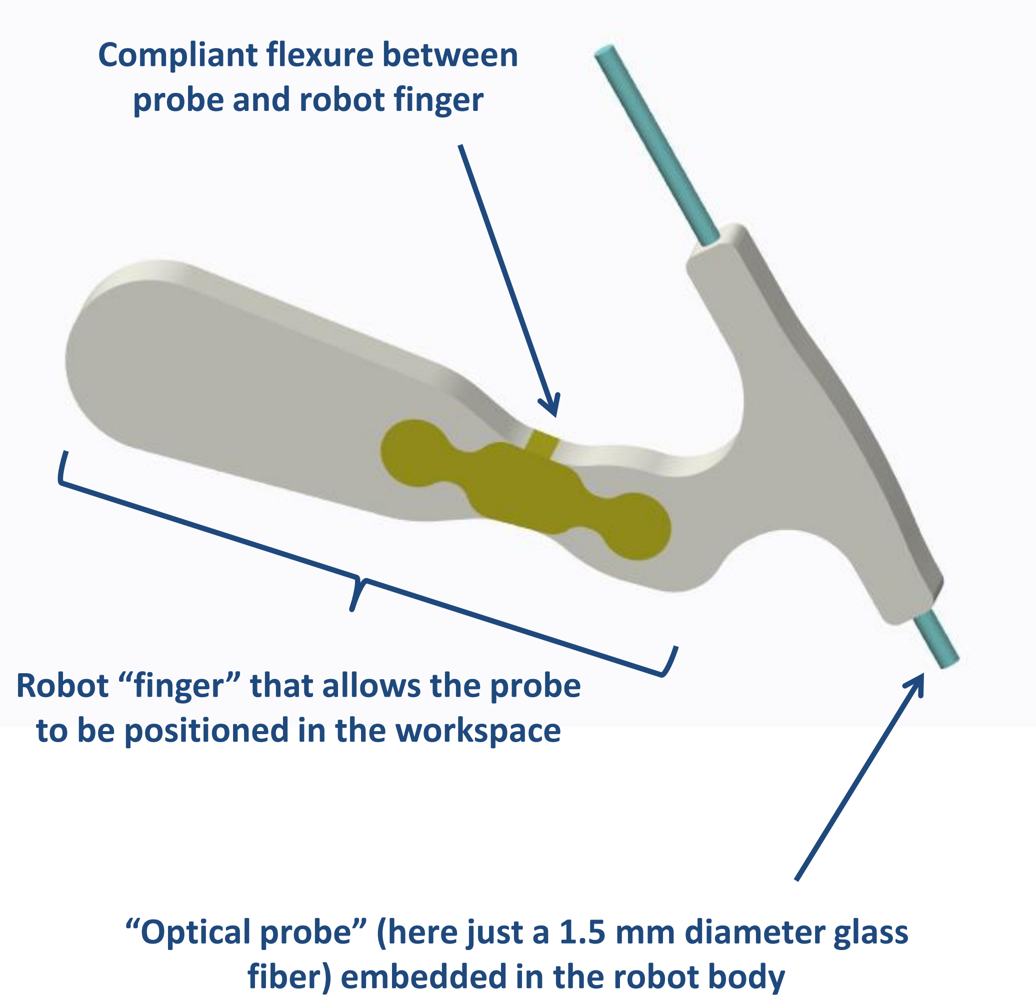
Thus, I was drawn to the **"Shape Deposition Manufacturing" (SDM)*** for ME 205 final project. Through this project, I explored:

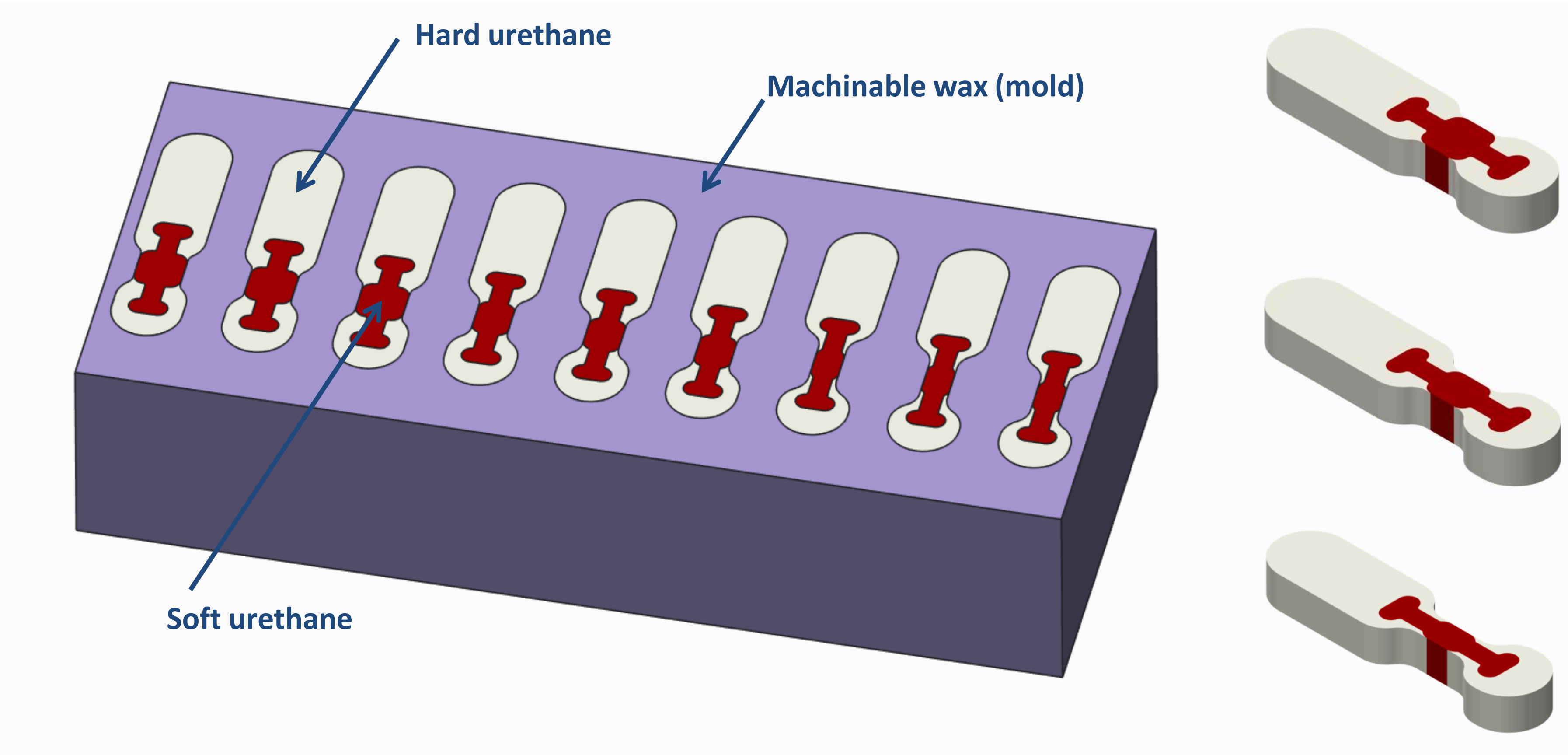
- **Sensor encapsulation** via pouring of hard urethanes (so-called "liquid plastic") around optical components.

- **Multi-material parts** that incorporate compliant flexures, implemented via the inclusion of soft urethanes in an otherwise hard urethane body.

Also, at the outset, I would like to thank **Eric Eason** from the Stanford BDML who very generously helped me get started with SDM.

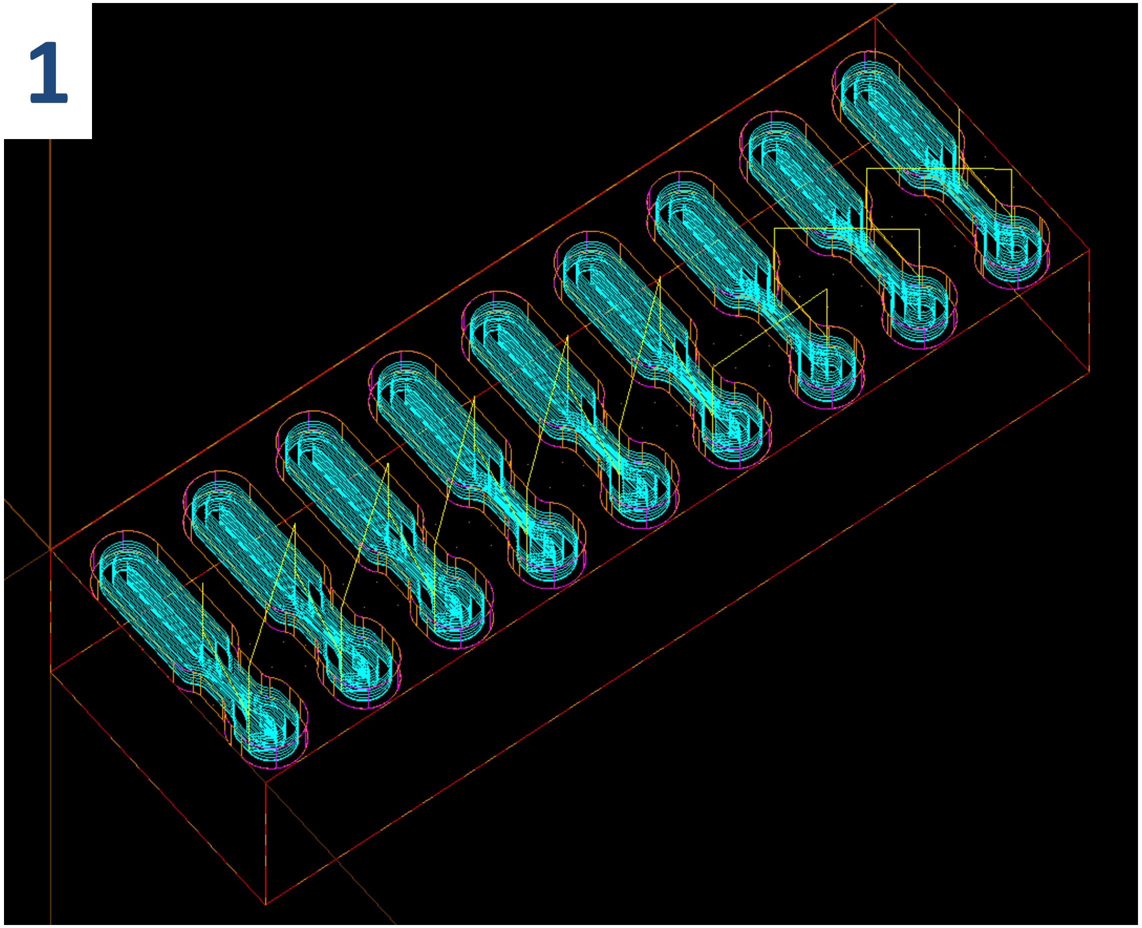
* Bailey, et al. "Biomimetic Robotic Mechanisms via Shape Deposition Manufacturing." ISRR (1999).





SDM Design #1 - Goals

With design #1, I wanted to become acquainted with the SDM process, and to construct basic flexure fingers using both hard and soft urethanes in a single part. Since I was not familiar with the softness of the “soft urethane” (Vytaflex 20 throughout this work), I also implemented flexures of varying dimensions.



SDM Design #1 - Process

The SDM process consists of multiple steps. Here is a step-by-step visual walkthrough.

1. **Begin by machining the mold (machinable wax) for the hard urethane**.
2. Pour hard urethane into the mold, wait 24 h for this so-called “liquid plastic” to cure.
3. Face the hard urethane.
4. Perform second machining step to define the mold for soft urethane.
5. Pour soft urethane into the mold. Wait 24 h for cure.
6. Peel off excess soft urethane.
7. Extract the part!

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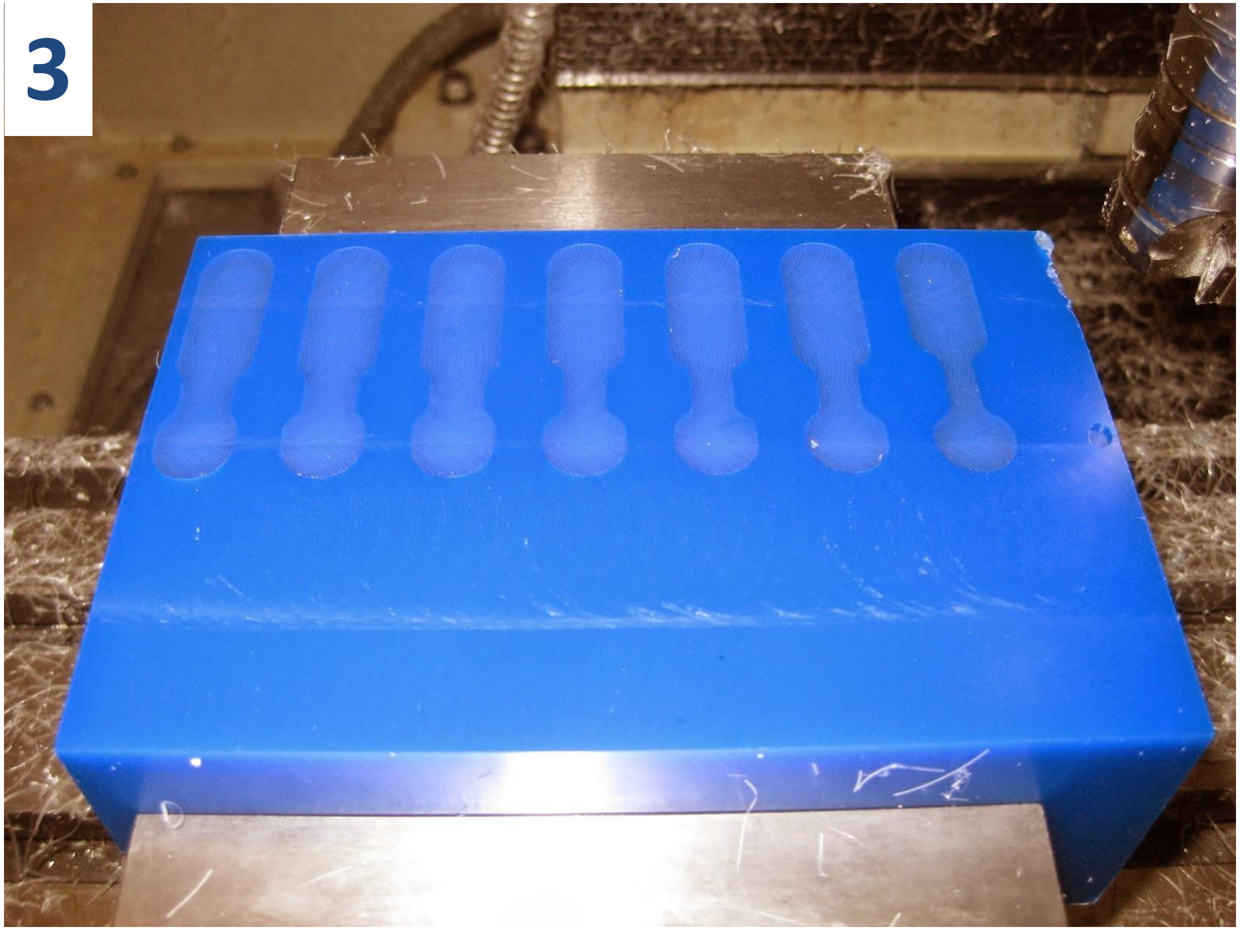

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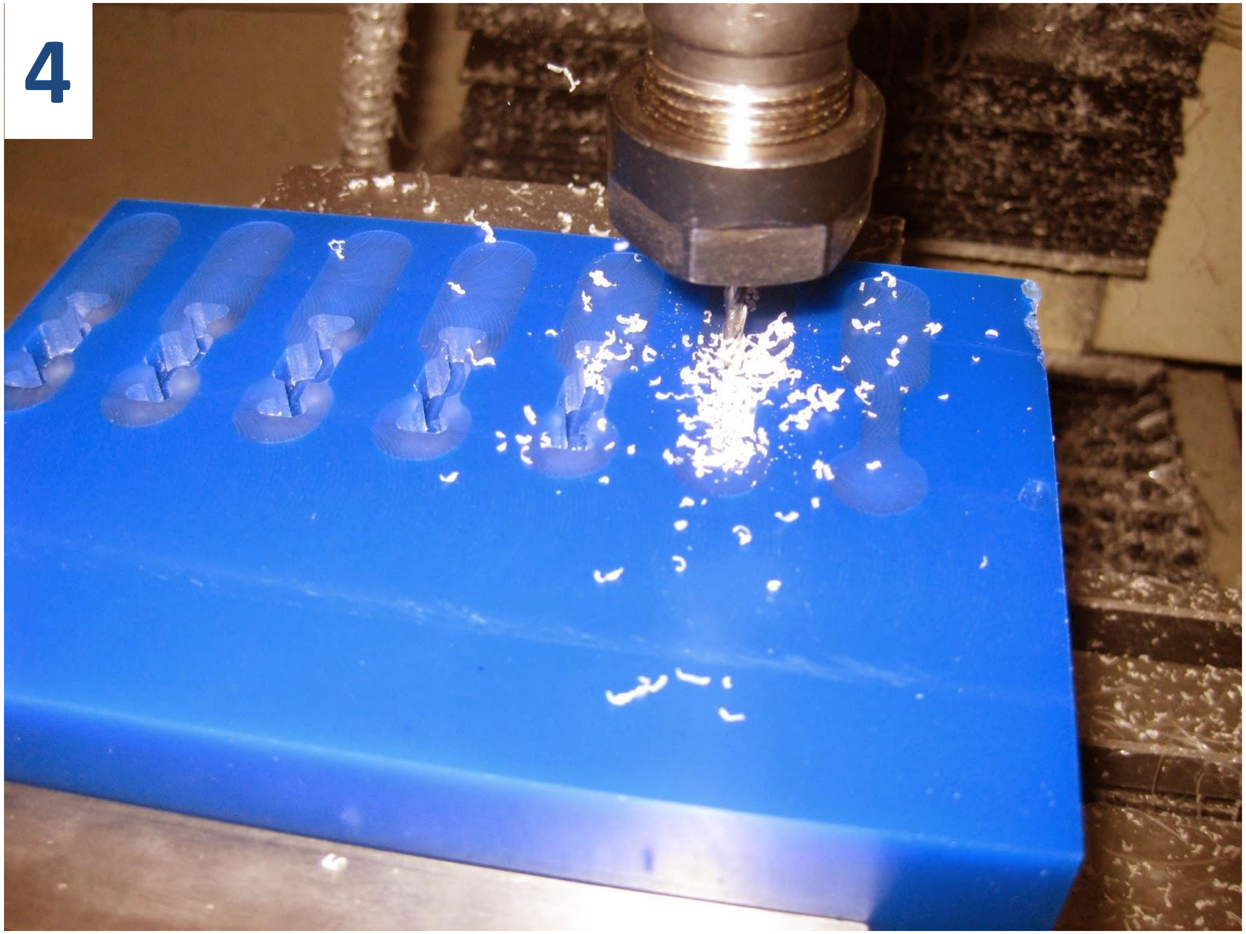

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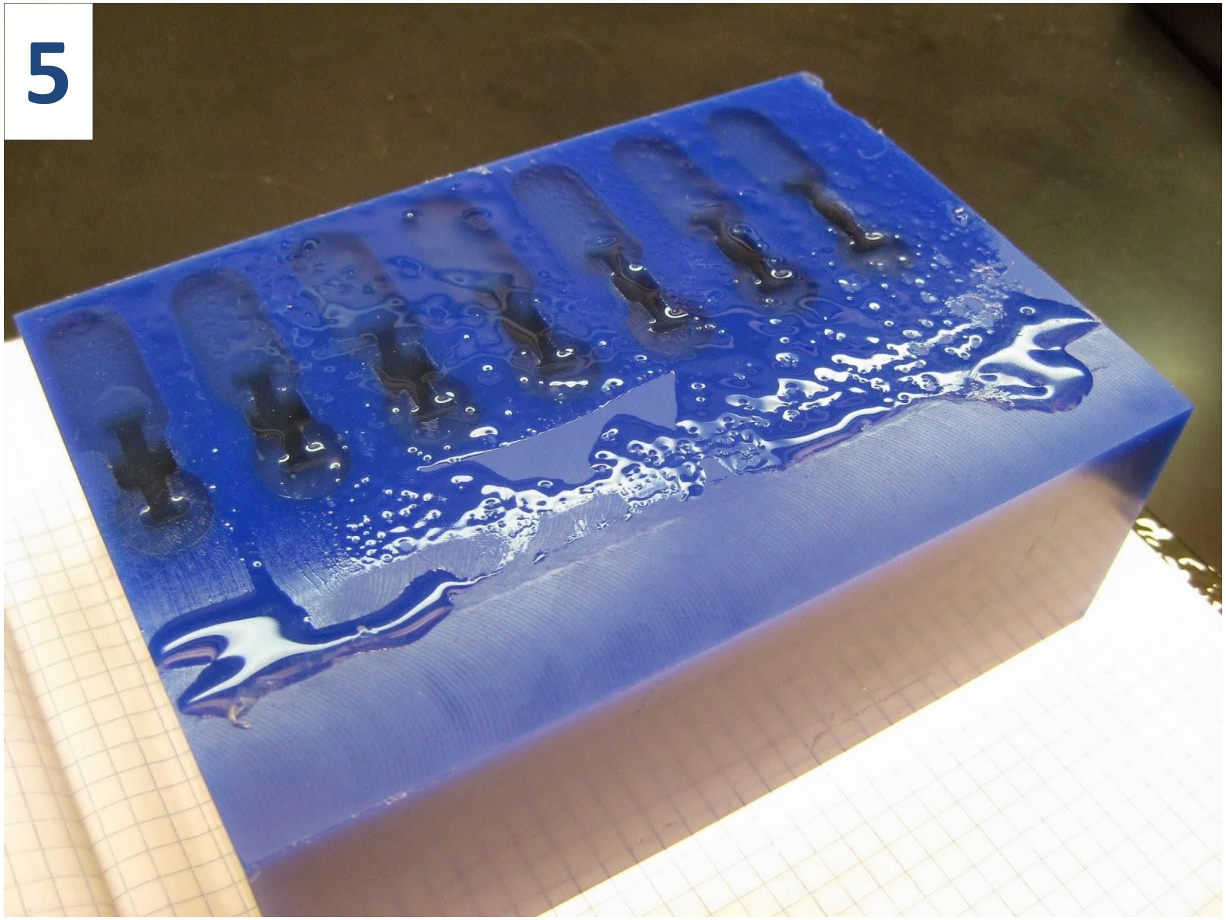

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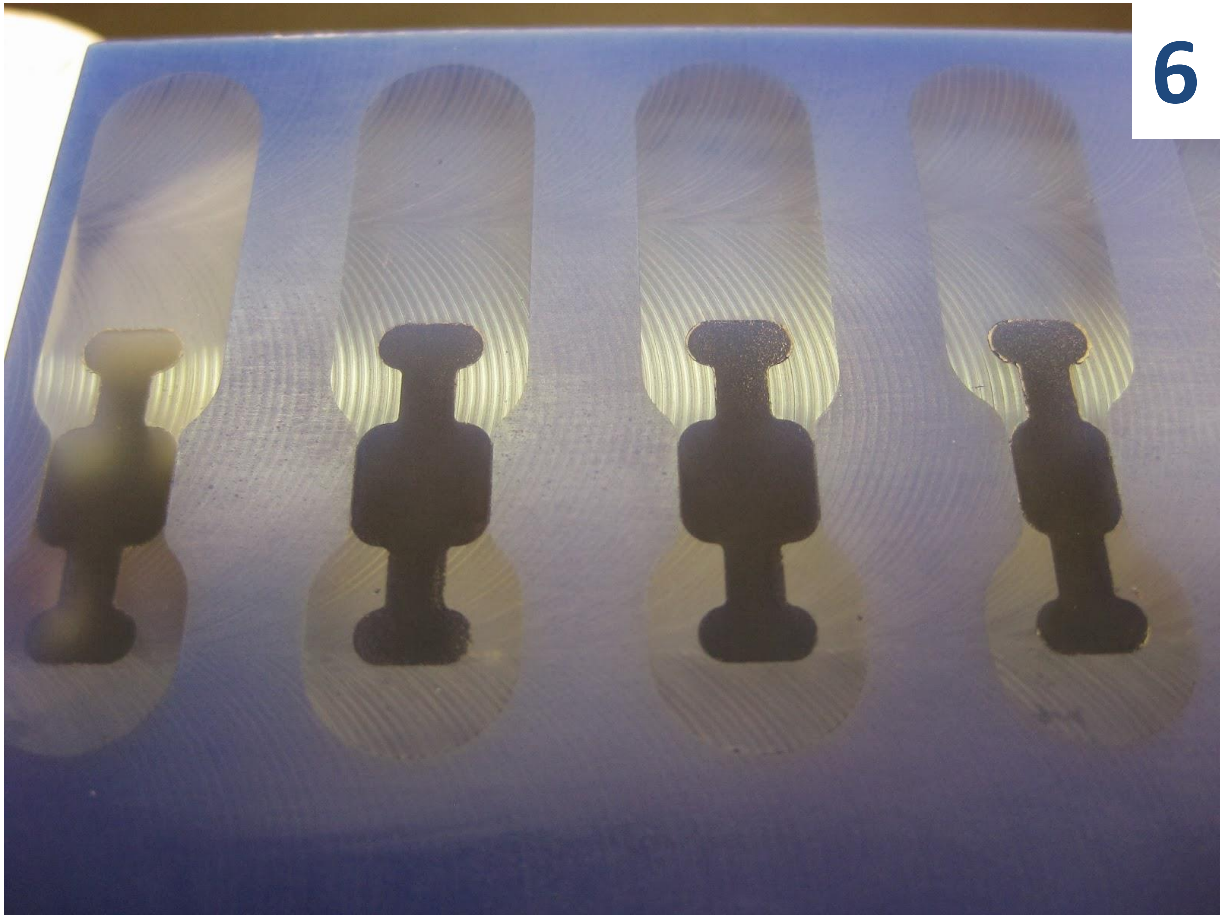

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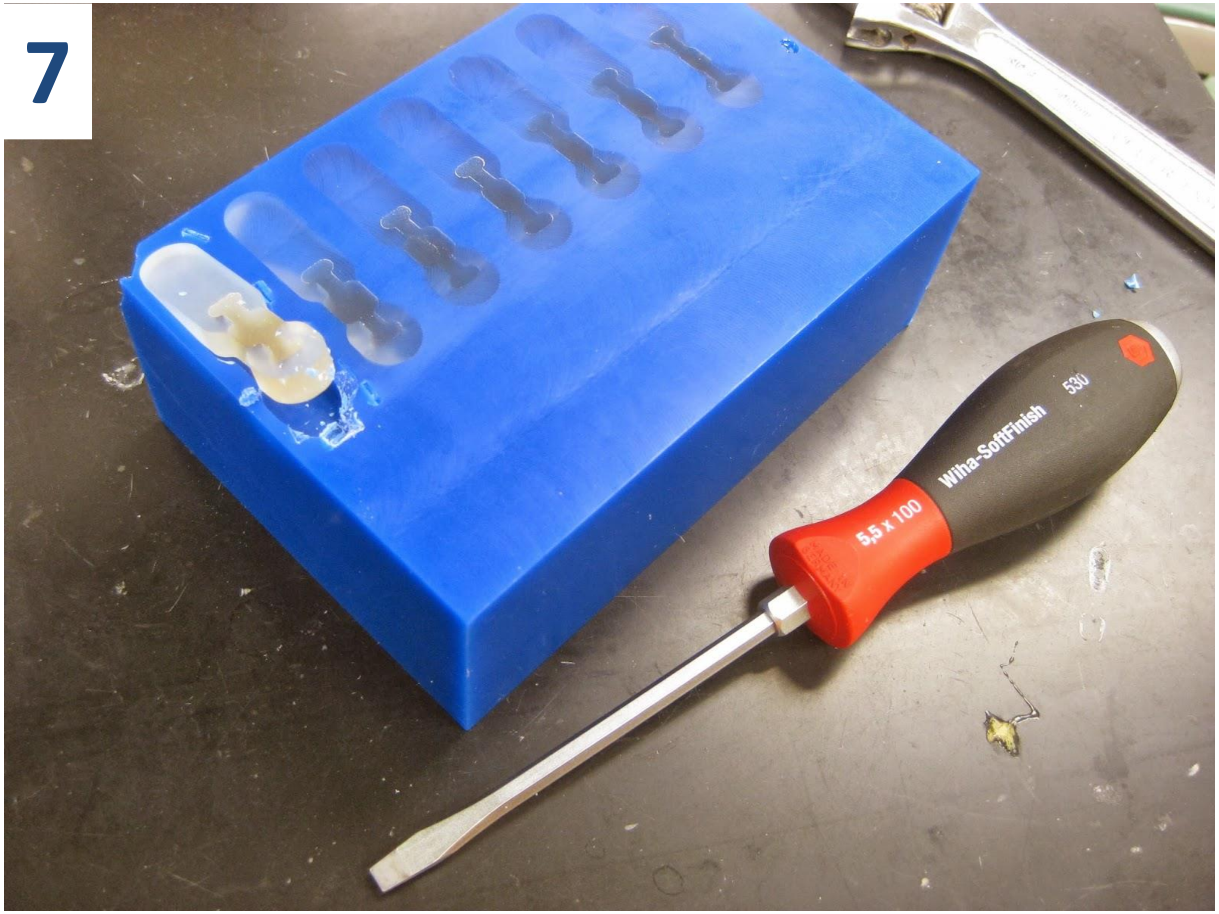

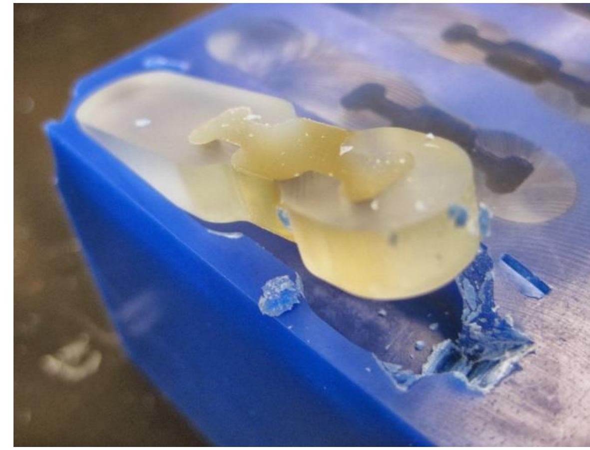

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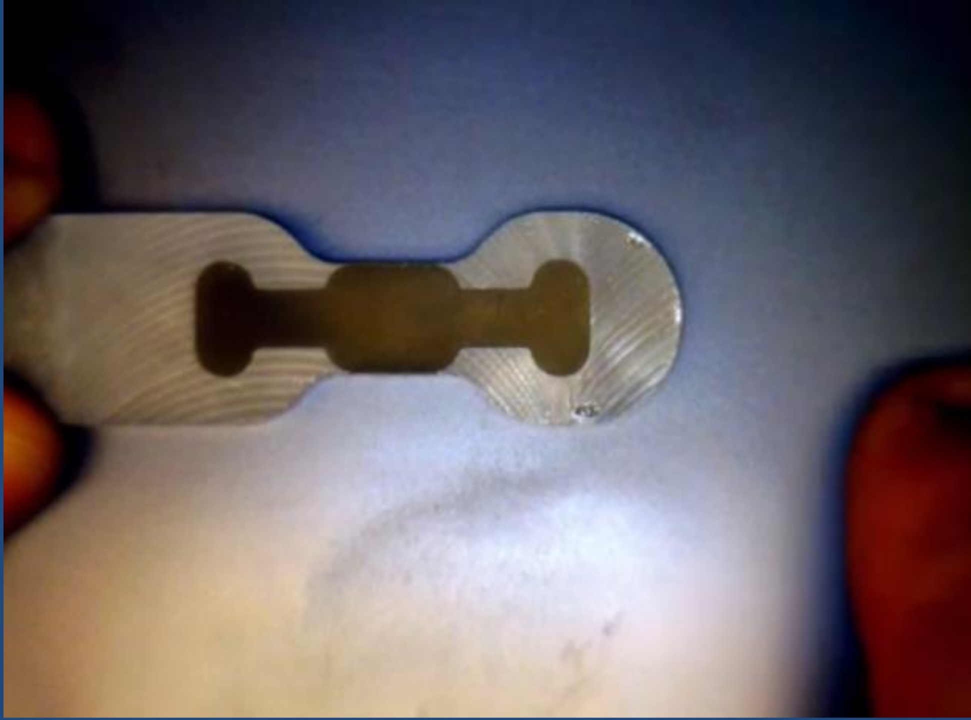
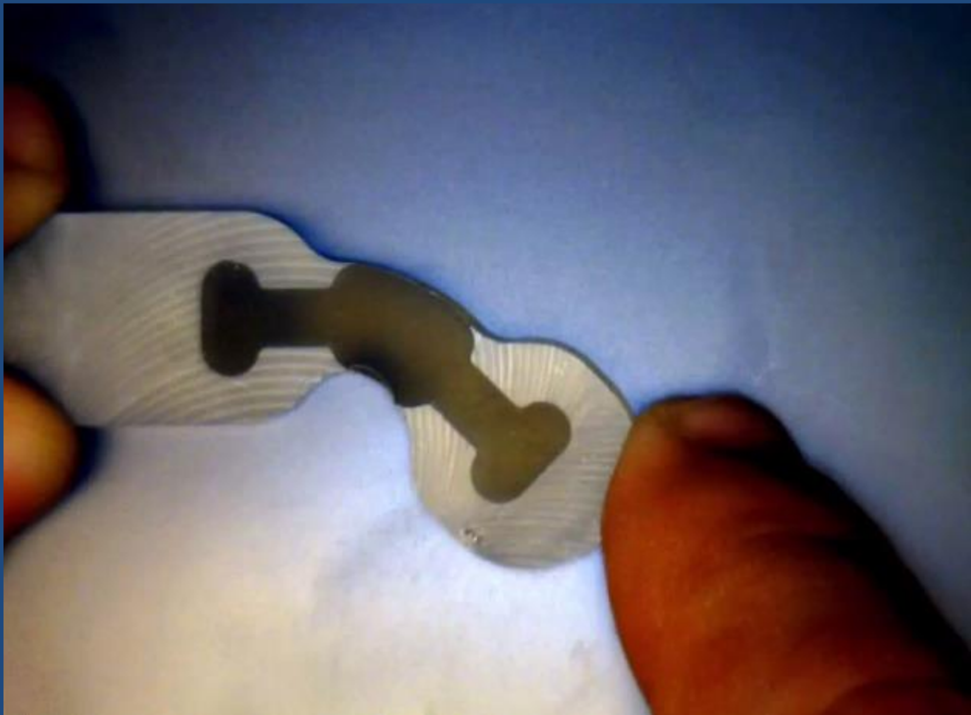
SDM Design #1 - Result

Despite the numerous steps involved (machining and pouring) for making a multi-material part, each step is very straightforward. It helps that the machinable wax is extremely pleasant to cut, and that the pre-cure urethane is very nonviscous (compared to silicones) so that it flows very easily into the mold.

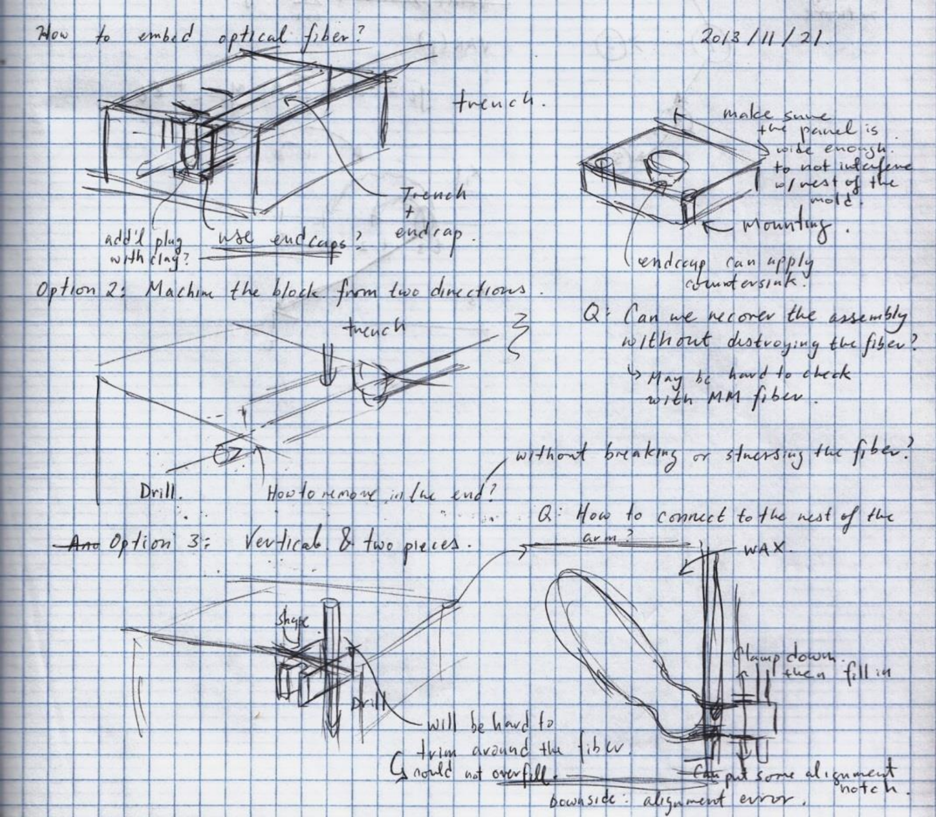
[Bottom] Freshly-extracted fingers.

[Right] Demonstration of the flexibility of the flexure.





SDM Design #2 - Goals



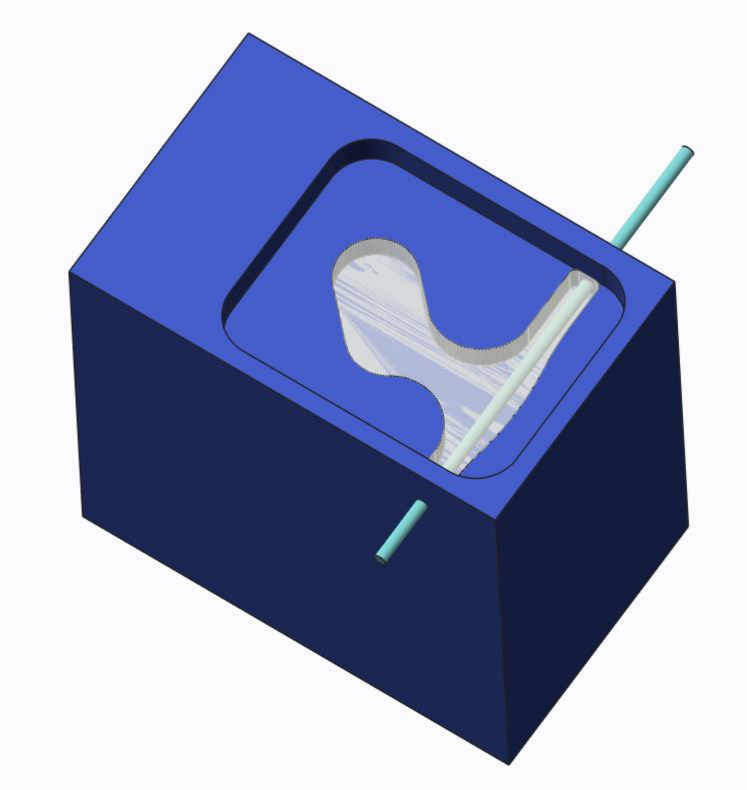
I was now interested in embedding an optical fiber into the hard urethane. Furthermore, I was also interested in exploring the different types of the hard urethanes.

[Left] Brainstorming various strategies for embedding an optical fiber.

[Bottom] I tabulated the available hard urethane plastics at Smooth-On. In particular, I was interested in the shrinkage of the material as it cures, since I don't want internal stresses to damage my embedded optical probe (in future work).

Urethane plastic	Description	Color	Hardness	Pot Life	Cure Time	Shrinkage (in/in)
TASK 2	"High strength, low viscosity"	White	ShoreD 80	7 min	60 min	0.0050
TASK 3	(Same as above)	White	ShoreD 80	20 min	90 min	0.0025
TASK 4	"Very strong in thin walled sections" (0.75 mm to 12.7 mm)	Ivory	ShoreD 83	20 min	16 h	0.0035
TASK 5	"Lowest cost performance plastics anywhere"	Tan	ShoreD 77	3 min	15 min	0.0070
TASK 6	(Same as above)	Tan	ShoreD 75	7 min	75 min	0.0031
TASK 7	"Flame rated - fire resistant urethane resin"	White	ShoreD 73	2.5 min	10 min	0.0111
TASK 8	"Heat resistant urethane plastic"	Off-white	ShoreD 80	2.5 min	10-15 min	0.0100
TASK 9	"Neutral amber for color matching and pigmenting"	Clear amber	ShoreD 85	7 min	1 h	0.0090
TASK 11	"Semi-rigid resin - dry food applications"	Translucent white	ShoreD 60	20 min	16 h	0.0024
TASK 12	"Virtually indestructable - highest impact resistance" DANGEROUS to work with!	Clear amber	ShoreD 60	20 min	16 h	0.0010
TASK 13	"Black semi-rigid urethane casting resins" Parts for impact resistance	Black	ShoreD 50	3 min	20 min	0.0050
TASK 14	(Same as above)	Black	ShoreD 50	10 min	45 min	0.0035
TASK 15	"For machine rotocasting - high impact resistance"	Opaque white	ShoreD 75	6 min	1 h	0.0042
TASK 16	"Fast-setting Shore 80A/30D industrial liquid rubber…"	Light yellow	ShoreD 30	6 min	90 min	0.0025
TASK 18	"Aluminum filled mass casting resin"	Metal gray	ShoreD 88	20 min	16 h	0.0006
TASK 21	"Customers have used to approximate ABS plastic properties…"	White	ShoreD 75	6 min	1 h	0.0058

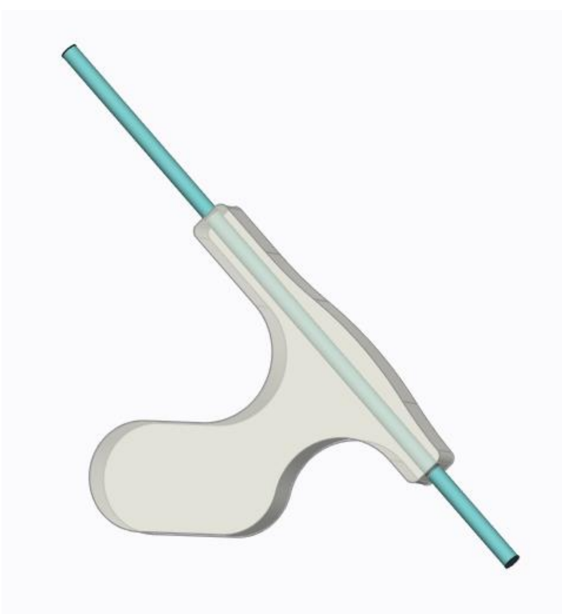
SDM Design #2 - Process



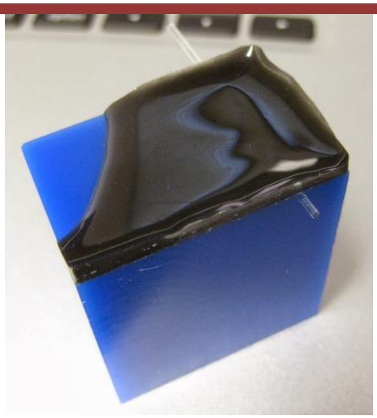
[Left] I chose to embed the fiber in the hard urethane by drilling a hole on the side of the mold. The fiber is inserted into this hole. By under-dimensioning the hole (by about 50 microns), the machinable wax made a very tight seal around the fiber.

[Left, bottom] Extracted part with an embedded fiber.

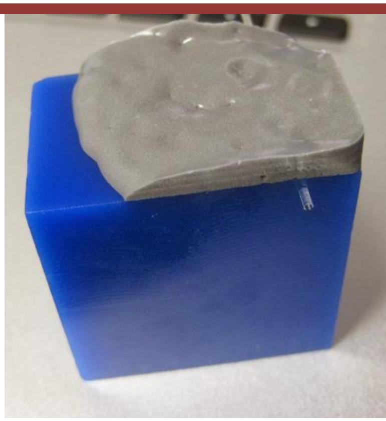
[Bottom] Poured Task 4 (white), Task 14 (black), Task 18 (gray). All are hard urethanes.



Task 4



Task 14



Task 18

SDM Design #2 - Results

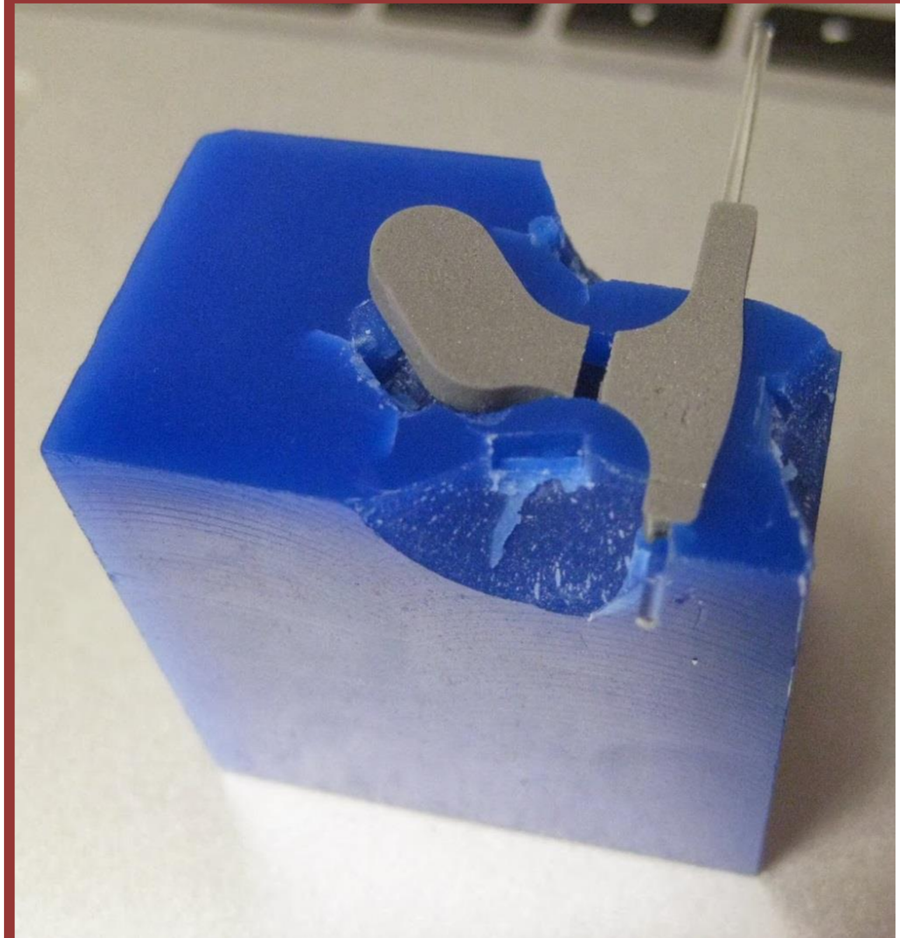
The task of embedding an optical fiber in the hard urethane also turned out to be straightforward, owing in particular to the non-viscous nature of the pre-cured urethanes (at least for Task 4 and Task 14). These flow almost like water!

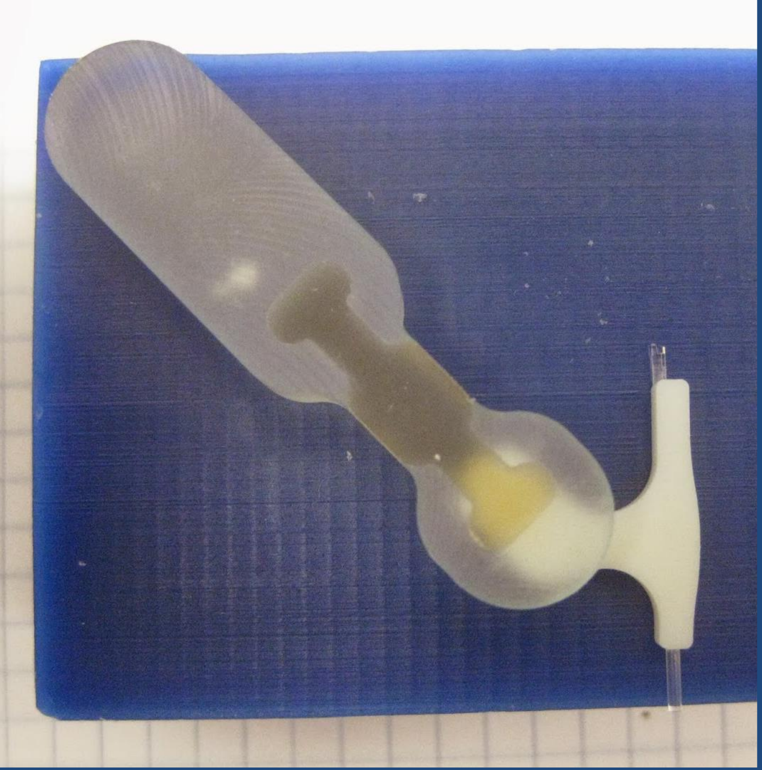
On the other hand, I encountered a number of problems in the resulting part.

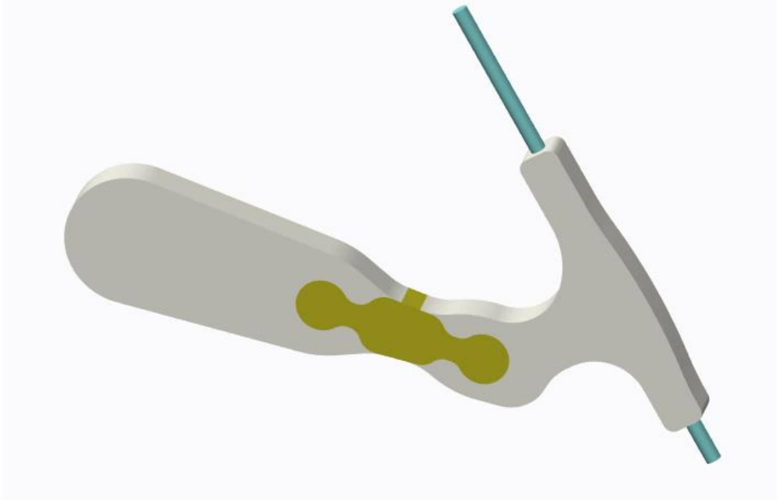
[Top right] Firstly, I had a miscalibration in the zero master (tool for positioning a part) of my CNC, and the via for the fiber was crooked with respect to the main pocket of the mold. As a result, the embedded fiber is not accurately aligned with the body.

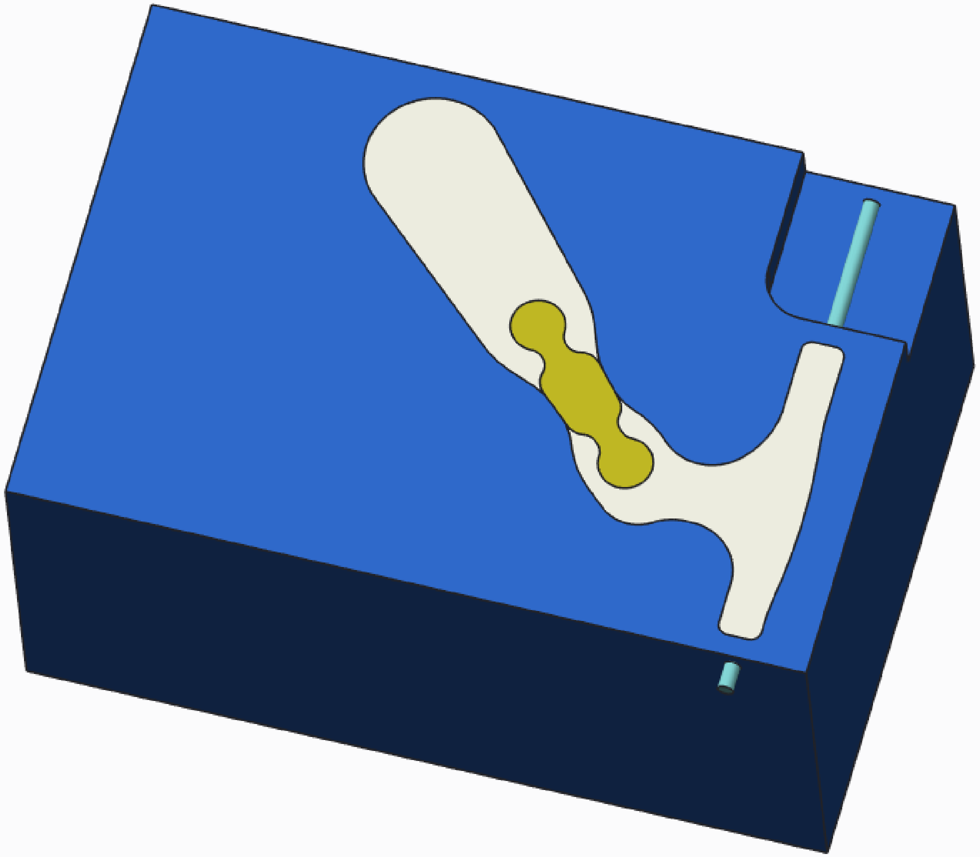
[Right] Secondly, I had improperly mixed the A/B parts for Task 14 and Task 18, and these parts did not cure appropriately. The Task 14 part (black) never cured and was not possible to machine, and the Task 18 part remained somewhat soft after 24 hours, which led to breakage during the extraction process.

Also, I concluded that Task 18, despite its excellent shrinkage properties, was too “pasty” to reliably flow into the small features in the mold that are necessary for my application.









SDM Design #3 - Goals

[Top] With the final design, my goal was to integrate the fiber-embedding feature of Design #2 with the compliant flexure of Design #3.

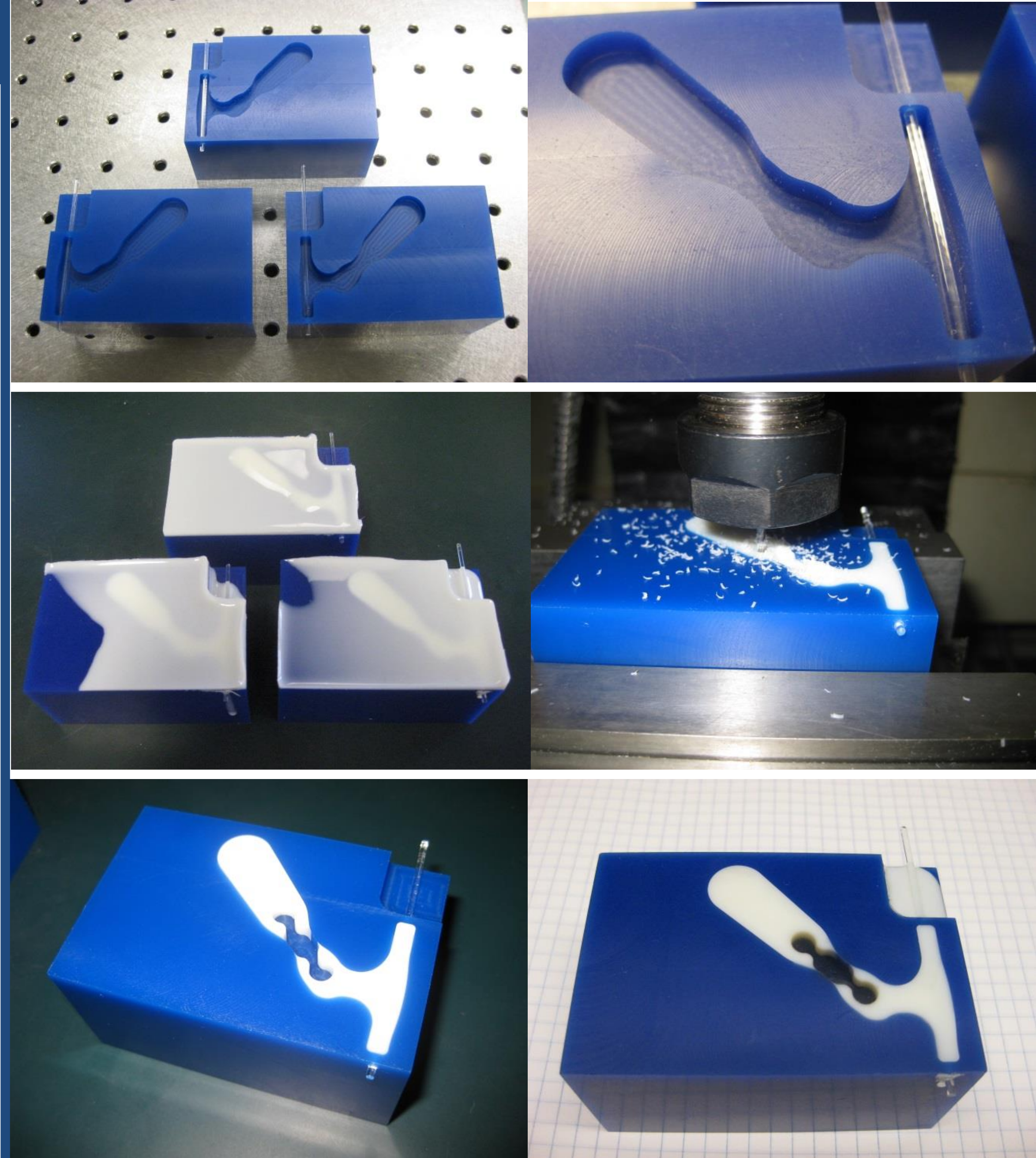
[Right] CAD of the combined design.

SDM Design #3 - Process

[Top row] Machining of the initial mold for hard urethane (Task 4). Optical fiber is held within the mold.

[Middle row] The mold following the hard urethane pour. Post machining includes facing of excess hard urethane, and then the definition of the mold for the subsequent soft urethane pour.

[Bottom row] Mold readied for soft urethane (Vytaflex 20) pour. Because the soft urethane is not machinable, the second pour just fills the pocket, and the excess is “squeezeed” off.



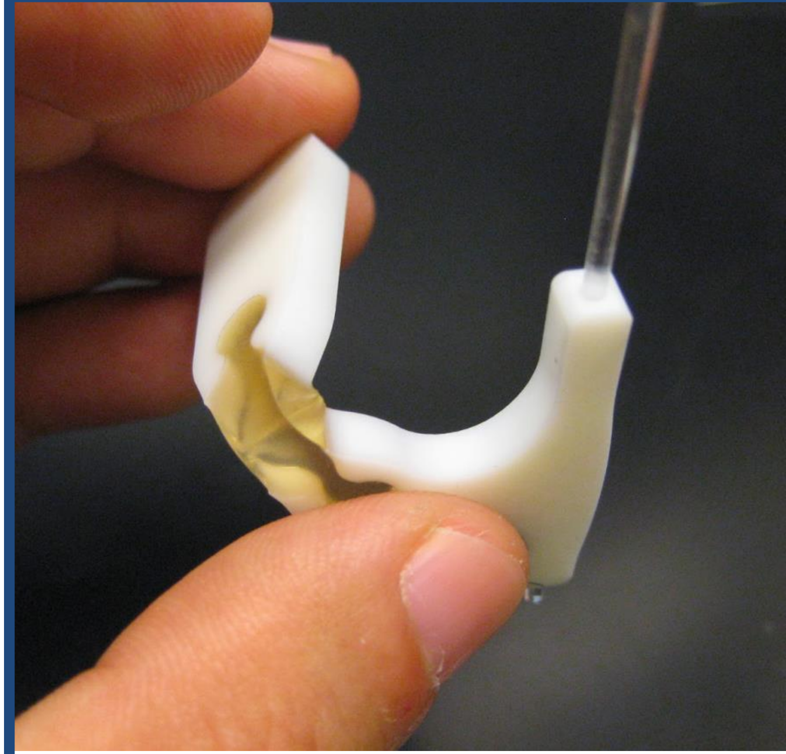
SDM Design #3 – Concluding thoughts

Use of "liquid plastic" for sensor embedding: I am very pleased with the ability of hard urethanes (prior to curing, of course) to flow into small features (~1 mm) needed for my design.

Additionally, I am very pleased with material properties of the cured urethane. It is quite rigid, and will – I believe – adequately protect the delicate micro-optics embedded in the structure.

Use of multi-material parts: I found the SDM process for building multi-material parts to be quite straightforward and robust. (It would be convenient to have the pouring station and the CNC machine in the same room! During this project, I had to *drive* across campus…) The use of multiple materials in a single part opens up a quite many design possibilities!

In this project, I implemented a basic flexure (see **top right**). One drawback of this design is that the fiber-grabbing end effector flexes willy-nilly in any direction (see **bottom right**). Also Vytaflex 20 is *too* flexible in the current design. I suspect that finding the "right" flexibility for my application will require some trial-and-error of the various Vytaflex variants (with varying durometers). Finally, it would be interesting to implement flexure designs that define a preferred direction of compliance.



SDM Design #3 – Future work

More work in embedding of micro-optics: The micro-optics assembly in my research work has a significantly more complex geometry than the simple optical fiber presented in this work. In fact, my optical probe consists of multiple parts that are connected via optical glue in a T-shaped geometry. As such, I expect to perform the following tasks:

- Mold design for embedding T-shaped sensors. (Clearly, a single hole in the side of the mold is not sufficient.) It may be necessary to investigate two-part SDM molds.
- Careful measurements of the curing process. As the sensor consists of multiple parts connected by optical glue, there is the possibility that the curing of the hard urethane may crack the underlying sensor assembly. I would like to perform more tests of the embedding process before sending $2000 probes into molds.

Alternate uses of the soft urethane: In this work, I implemented a simple flexure joint to accommodate potential collisions. This is, however, an undesirable strategy for an optical instrument that must hold its static position rigidly at the micron-level. Instead, I am interested in the use of soft-urethanes as exterior “bumpers” to dampen collisions. This way, we do not give up static rigidity to obtain compliance to collisions.

Acknowledgements

Once again, I would like to thank Eric Eason from the BDML for his generosity in getting me started with SDM, which included starter materials, space in lab to pour (toxic) urethanes, and design advice!