

Department of Electrical Engineering and Computing System (DEECS)

Soft Robotics: Comparing Designs of Soft End Effectors

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Dedication

We would like to thank the following:

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Abstract

Soft robotics is a budding new field of engineering with multiple potential applications where soft robots could be more effective for less cost than their hard counterparts. The current problem with widespread implementation is a lack of information about the strengths and weaknesses of different types of soft robots. Experimentation is needed to give future contributors to the field a baseline to start from. To address the lack of information pertaining to soft robots, we have gathered relevant data on the strengths and weaknesses of three different soft robotic end effectors by fabricating and testing each end effector against a control based on various testing criteria. By doing so, we hope to provide information that can be used in future senior design projects related to soft robotics.

Introduction

Soft robotics is a relatively new and growing field of engineering that utilizes flexible materials in construction. Actuation is often designed to mimic the way living organisms move, and is achieved through a multitude of different means, including air pressure, tension of cables, and electric current.

There are multiple potential applications where soft robots could be more effective for a lower cost than their hard counterparts. The use of compliant materials gives them a greater range of motion, and depending on the design, can make them

much more durable. The soft nature of them makes them safer to work near in settings such as manufacturing. They can also be used to create devices for medicine, serving as less intrusive devices for invasive surgeries due to their ability to contort and smaller Bio-MEMS (biological microelectromechanical systems) for monitoring in vivo.

Problem

Research is important for the development of new technologies. Research is built upon by further research until eventually there is enough information to develop a finished product. Our original idea was to create a soft robot, but in trying to select a type of robot to create we encountered something more significant: the current largest problem with the widespread implementation of soft robotics is a lack of information. There is no dichotomy of soft robotics designs that tell what actuation method or material perform better in different situations. Experimentation is needed to give future contributors to the field a baseline to start from.

Solution

In order to solve the problem we encountered of there being a lack of information, we fabricated three different end effector designs that we pulled from various resources in order to conduct multiple tests. These tests compared our fabricated designs to controlled designs as well as comparing the similarities and differences between each other to find design superiority. With this, we were able to show

which end effector would be most efficient for a soft robotic design with results to back up our findings.

Credibility

Jacob Cook: Jacob focused primarily on project management and fabrication for this project. While at UC, Jacob has successfully completed several courses relating to robotics, controls engineering, and data acquisition. These courses helped him utilize fabrication procedures, adapting them to the project at hand and aiding to the development of a testing procedure. As for work experience, Jacob has completed five co-op rotations; two with Intelligrated working in electrical design of materials handling systems, two with EN Engineering working on electrical infrastructure upgrades, and one with NSG Pilkington working on upgrades to control systems and HMI design.

Jordan Laley: Jordan's primary focuses on this project were her use of electrical engineering skills from previous class work, implementation and fabrication, as well as software design. While at UC, Jordan has completed multiple co-op terms that involve the use of problem solving and implementation skills. Jordan has also completed coursework that directly correlate the work done on this senior project, for example a Solidworks course which helped her be able to design the needed 3D- printed mold for the X-Gripper end effector.

James Keeney: James was brought in from his Computer Science major for his knowledge of code and prior work in embedded systems. His prior projects involved having to learn the specifics of a system within a microcontroller, which could be applied to the operation of the uArm robot. James's experience with JavaScript also helped in understanding the way the uArm's proprietary code compiled, as options to view and work with JavaScript were also available.

Joshua Ohm: Joshua's main focuses in the project were documentation and experimentation. Joshua has completed three co-ops that dealt heavily with electronics and quality control, as well as several classes with labs that involved experimentation and data acquisition, which he was able to use in completing the testing process and documentation of results in this project.

Project Goals

The main objective of this project is to obtain more information pertaining to different types of soft robots. By fabricating and experimenting with these end effectors, we plan to provide a basis of information for future projects related to soft robotics, specifically senior design projects. We also hope to provide information related to the strengths and weaknesses of each end effector we studied. Students, researchers, and anyone interested in using soft robots will be able to use the data acquired from our project to make a decision of what kind of end effector would work best to fulfill their needs.

Discussion

As previously stated, our project involves the fabrication and testing of three different soft robotic end effectors. The three end effectors we decided to work with are the knit textile bending actuator, the X-gripper, and the SDM finger. The knit textile actuator is a balloon wrapped covered by a sock with cotton on one side and spandex on the other side. When the balloon inflates, the applied air pressure bends the actuator in the direction of the spandex. The X-gripper is an x-shaped end effector made up of silicone rubber molded by a 3D-printed mold. The gripper has air channels inside of it, and when inflated, the arms of the gripper bend in the direction of the thinner side of the silicone, which allows the gripper to pick up objects. The SDM finger is a finger-shaped end effector made up of molded silicone rubber and a cord that runs inside the silicone. When the cord is pulled, the finger bends and is able to pick up objects.

Project Concept

Our project is focused on gathering information on different end effector types in order to provide value to future soft robotic designs. This was done by gathering data from multiple resources and fabricating three different end effector design to be tested. As previously stated, the designs chosen were the knit textile bending actuator, the X-Gripper, and the SDM finger. These designs were then fabricated

and tested against each other as well as two other controlled grippers. Through these tests we were able to see which end effector measured up to the controlled grippers as well as which end effector would be deemed most efficient in future soft robotic designs.

Design Considerations

Several End effector designs were considered in prototyping, but the list was narrowed down to three using several criteria:

- **Budget** - The project was intended to serve as a baseline for future research, and in order to keep it viable for future groups to replicate the designs, especially with possible similar budgetary constraints, designs using expensive materials such as dielectric polymers were eliminated.
- **Required Equipment** - In a similar vein, specialized equipment for fabrication was a consideration. As the most likely groups to use this as a baseline are students, equipment required would need to be limited to what could reasonably be available at an academic or similar institution, like 3D printers or voltage sources, or fairly inexpensive, like a glue gun.
- **Repeatable Fabrication** - It was important to select end effectors that could be made consistently and repeatedly, with low chance for defects, as a difference in quality would skew results.
- **Time Required** - The short turnaround time was a factor because of this experiment, as multiple copies of multiple different end effectors needed to

be made, so a long fabrication time would be much more significant in bogging down the process than a single more involved end effector.

- **Practicality of Actuation** - The goal was to test end effectors that could potentially have real world application one day, so any means of actuation that either didn't have the ability to move a large amount relative to energy exerted or had obstruction in its ability to manipulate objects wouldn't be practical for the project.
- **Variety** - The focus here was on making sure there were multiple types of actuation methods and materials used so as to cover a variety of potential applications.

Standards

Within the constraints of the experimentation, there is a certain acceptable standard that needed to be considered to ensure the validity and quality of the results. By outlining standards to adhere to, we can ensure that the project was completed with a definitive level of acceptance when conducting experiments.

- **Design Standards** - Due to the exploratory nature of this project, there was a lot of designs to consider moving forward with. One standard implemented for determining the best designs to move forward with was considering the similarities of the end effectors. Choosing end effectors that use different methods of gripping allow for a wider scope of testing. Pneumatic systems were fairly common amongst designs due to the compressible nature of air.

This is favorable for soft robot designs because air provides a cushion for degrees of movement, which is an essential quality of soft robots. Including end effectors that work with another system (such as strings) was essential to show to be able to compare with the pneumatic systems we chose.

- **Fabrication Standards** - Standards for the fabrication process were created to ensure that the end effectors were made with the least amount of error. Each end effector went through an initial test fabrication, allowing for the familiarity of the material. The test fabrication is expected to have errors, and by identifying the errors in the tests, another round of fabrication can be done while specifically making sure the errors are accounted for. Additionally, testing each end effector before before conducting experiments on them highlighted any deficiencies in the end effector. By continuing this process, eventually an end effector with little to no errors is created, and can be used for testing.
- **Testing Standards** - When conducting tests, standards had to be created to verify the integrity of the results. Without standards for this step of the research process, it's easy to accept inaccurate representations of the end effectors. One such standard was to choose tests that would represent the widest array of metrics across the end effectors. Some of the chosen designs work best in ways that others would not. While one design might not excel at grip strength, it might excel in other fields like dexterity or ease of fabrication. By spreading out the tests across different fields, we can compare and contrast the positives and negatives of each end effector. Another

standard that was implemented was the process of repeating the tests. In one example, an end effector was not able to pick up an egg on its first try. However, after subsequent attempts, the end effector was able to reliably lift it. If a single test was performed, the end effector would have been marked down for its dexterous ability. However, because of the standard implemented, it was considered able to lift the egg and therefore pass with a better representation for its ability.

Budget

The fabrication of the soft end effectors comes with a price. Figure 1 details the associated expenses for the materials that were used.

Item	Quantity	Total Price
Tubing (1/4" OD)	10 ft	\$3
Tubing (3/8" OD)	10 ft	\$3
Silicone Rubber	3 lb	\$35
Kevlar Cord	10 ft	\$5
Hot Glue Gun	1	\$8
Extra Glue Sticks	12	\$1.50
Blood Pressure Cuff	1	\$15
Baking Sheet	1	\$5
Electrical Tape	1 roll	\$2
Glue Stick	1	\$2
TPE Sheets	1 sq yd	\$20
Flexible Adhesive	1 fl oz	\$7
Spandex	1 sq yd	\$5
TOTAL		\$111

Figure 1: Itemized breakdown of tools and materials, with associated quantity and total price.

Soft Robotics: Comparing Designs of Soft End Effectors

The extent of the budget includes materials that were invested into the fabrication of each end effector. This budget includes expenses that had to be personally covered by individuals of the group. It does not include tools and materials that were made available by UC facilities (e.g. 3D Printer, 3D printer filament, uArm Swift), or common items of unsubstantial value (e.g. shirt fabric, scissors, cardboard). Actual budgets for future iterations of this project may vary by a sizeable margin depending on the amount of attempts of fabrication, or if the availability of the aforementioned tools and materials changes. If more attempts at fabrication are made, then the extra cost of materials must be considered. Consideration for the variation of the budget is discussed later in this document.

Timeline

When the Senior Project first began on October 1st, 2018, a Gantt Chart was constructed in order to keep track of the group's progress. Our group mainly stayed consistent to the schedule, with just a few minor adjustments and occasional updates to the chart during the desired time frame. The last update was made to the chart a few weeks before our first 4 minute presentation, resulting in the finished Gantt Chart schedule. The final Project Gantt Chart is shown below in Figure 2.

Soft Robotics: Comparing Designs of Soft End Effectors

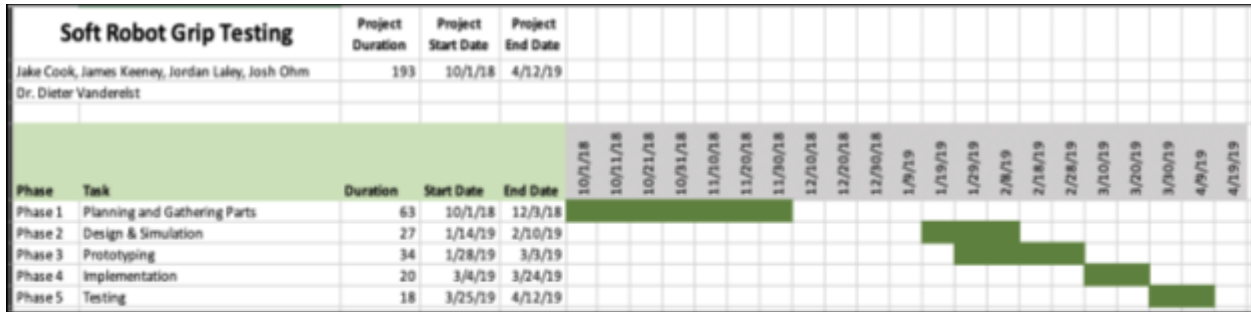


Figure 2: Project Gantt Chart

As shown, Planning and Gathering Parts was the longest phase of the five. The planning and gathering process took time due to the lack of information given on soft robotics. Through research, we were able to find multiple resources that allowed us to gather the data needed to fabricate our end effector designs. After break, we regathered as a group and immediately began working on the design phase. Prototyping came soon after, with some of the time frame overlapping design and simulation. This overlap was feasible due to having staggering finishing times of each end effector design. The last two months of the project were dedicated to implementation and testing. Testing was the finishing aspect that tied our project together, allowing us to review data and determine which design reigned superior to the others.

Results

Once all materials were gathered and all end effectors were fabricated, each end effector was judged based on its overall cost of materials and the ease of its fabrication process. Each end effector's ease of fabrication was judged based on

time required, failure rate, skill required, budget parts modularity, and cost of materials. The breakdown of different aspects of the fabrication process is shown in Figure 3.

The SDM finger had the least active time required for fabrication with 1 hour, followed by the knit textile actuator with 75 minutes, and the X-gripper with 2 hours. The knit textile actuator required the least passive time in its fabrication process, since it did not require any passive time at all. The SDM finger followed with 75 minutes, and the X-gripper required the most passive time, 150 minutes. Because the knit textile actuator did not require any passive time, it had the overall shortest time of fabrication at 1 hour and 15 minutes. The SDM finger was second with 2 hours and 15 minutes, and the X-gripper had the longest fabrication process at 3 hours and 30 minutes, which is the same amount of time as the other two end effectors' times combined.

The knit textile actuator had the lowest failure rate, with one working actuator fabricated in two trials. The SDM finger had the second lowest with two working fingers fabricated in six trials. The X-gripper had the highest failure rate because out of three trials, a working gripper could not be fabricated.

It was determined that the knit textile actuator required the least skill to fabricate because it was the only end effector that did not require making a mold and pouring silicone rubber into said mold. Instead, it merely required sewing and the use of a hot glue gun. The SDM finger was given the second best skill rating because while it required molding silicone rubber, the molds could be made with cardboard. The X-gripper was decided to require the most skill because in addition

to requiring the molding of silicone rubber, the gripper’s mold had to be 3D-printed, which required knowledge and experience in SolidWorks.

The knit textile actuator was given the highest budget parts modularity rating because it was fairly easy to find cheaper alternatives for materials required in fabrication. For example, the non-stretchy fabric used to make the actuator was taken from an old T-shirt instead of new fabric being purchased. The SDM finger and X-gripper were given lower ratings in this area because it was more difficult to find cheaper substitutes to their required materials.

The knit textile actuator had the lowest cost of materials at \$22, followed by the SDM finger at \$45 and the X-gripper at \$60. The SDM finger and X-gripper were costed more to fabricate than the knit textile actuator because they both required silicone rubber, and the X-gripper was more expensive than the SDM finger because the mold costed more to make.

	Fabrication					
	Active Time	Passive Time	Failure Rate	Skill Required	Budget Parts Modularity	Cost
Knit Textile	75 minutes	0	50% (2 trials)	7/10	8/10	\$22
SDM Finger	1 Hour	75 minutes	60% (6 trials)	6/10	4/10	\$45
X-Gripper	2 hours	150 minutes	100% (3 trials)	4/10	4/10	\$60

Figure 3: Breakdown of fabrication and price point results

After fabrication was completed, multiple tests related to dexterity, strength, and speed were conducted on the end effectors, as well as the claw and vacuum gripper. The dexterity tests involved each end effector attempting to pick up four different objects: a block, an egg, a sheet of paper, and a pencil. The strength tests measured

how much mass each end effector could hold. Two strength tests were performed: load, which was parallel to the end effector, and mass, which was perpendicular. Lastly, the speed test compared the grip speed of each end effector. The data recorded from these tests is shown in Figure 4.

The vacuum gripper was able to pick up all other objects except for the pencil. Initially it failed the block test when a styrofoam block was used, but passed the same test when a wooden block was used. The claw was able to pick up all objects except for the paper. The knit textile actuator was able to pick up the egg, but nothing else. The SDM finger successfully picked up the block and the egg, but failed the paper and pencil tests. Similarly to the vacuum gripper, the X-gripper was able to pick up all objects except for the pencil.

The claw performed best overall in these tests, lifting 800g in both load and shear, and the vacuum gripper was second best, lifting 600g load and 350g shear. Of the soft robotic end effectors, the SDM finger performed best, lifting 350g load and 250g shear. The knit textile actuator lifted 80g load, but was unable to hold any shear mass. Because a working X-gripper was not successfully fabricated, accurate strength tests could not be performed on it, so no data for the X-gripper's strength is listed.

Each end effector was then ranked from fastest to slowest. The vacuum gripper was the fastest, the SDM finger was the second fastest, the knit textile actuator was the third fastest, and the claw was the fourth fastest. Once again, because a working X-gripper could not be fabricated, an accurate speed test could not be performed, so the X-gripper was ranked last in speed by default.

		Dexterity				Strength (g)		Speed
		Block	Egg	Paper	Pencil	Load	Shear	
Control Grippers	Vacuum Gripper	?	✓	✓	✗	600	350	1st
	The Claw	✓	✓	✗	✓	800	800	4th
Test Grippers	Knit Textile	✗	✓	✗	✗	80	0	3rd
	SDM Finger	✓	✓	✗	✗	350	250	2nd
	X-Gripper	✓	✓	✓	✗			5th

Figure 4: Breakdown of Dexterity, Strength & Speed Results

Problems

While working on this project, we encountered a significant number of problems along the way. We had originally aspired to create a soft robot instead of just three different soft robotic end effectors, but because there is so little existing information about different types of soft robots, we were forced to take the project in a slightly different direction. The scope of our project was also limited by our relatively small budget, and because we had to fabricate each end effector multiple times, we ended up spending more than our listed budget as well.

We also ran into a number of difficulties during fabrication. Half of the SDM fingers we attempted to fabricate did not survive the molding process, and it was difficult threading the kevlar cord into the fingers after molding was completed. As stated previously, we were also unable to successfully fabricate a working X-gripper. The first two grippers fabricated did not have all of the air channels they needed because some of the air channels filled in, and the third gripper fabricated had an air bubble in it, which caused all of the air to rush to that one spot,

eventually popping it. We later fabricated a fourth X-gripper that also had an air bubble after finishing testing, but we were able to inflate the other channels by taping down the arm with the air bubble. We also had trouble inflating the knit textile actuator. The air pump we used likely was not powerful enough, and sealing the balloon and the pump proved to be difficult as well.

Lastly, we ran into an issue with the uArm on the day of the expo. Instead of following the code as it was supposed to, the arm would just shake violently when in certain positions. Fortunately, this did not affect us too much as we were still able to present our project fairly well, despite the technical difficulties.

Conclusion

The purpose of our experimentation process was to build the foundation upon the knowledge of soft robot end effectors. Early on, we realized there was no way to say which of these end effectors was objectively the best out of all the others. Rather, this data serves to highlight the realistic expectations one can expect when fabricating and using of each end effector. The vacuum gripper was the best at controlling, as it was built upon an existing system for movement. It also proved to be the fastest at actuation because of its built in pneumatic system. The SDM finger was the most reliably operational, and with a different setup provides the most promise for development in its current form. The knit textile bending actuator was the best functional pneumatic system and the most cost-effective to fabricate. It

was also the fastest to fabricate (with the knowledge of sewing). The X-gripper was the most difficult to fabricate and had the highest failure rate, therefore the least effective at testing and gathering data for. Rather than see this as a failure, we consider this to be a start to further understanding of the X-gripper's capabilities in future iterations of its design.

Future Work

Our original plan for senior design was to create some type of soft stunt robot, but in researching we realized the necessity to create a foundation for projects to come, providing information to help inform the choices of those who wanted pursue projects in the field by finding the strengths and weaknesses of different designs. From here, the two most obvious paths are to narrow the scope to one end effector, focusing on making a more complete and working system, or to broaden the foundation laid by similarly testing more end effectors to make for a more comprehensive baseline.

Narrowing the scope of the project would be in line with its original intent. Any of the three end effector designs could be expanded upon to make its own project:

- **The knit textile bending actuator** that we created uses a single balloon with a single fabric pocket to bend, allowing it to bend only in a single direction. Clustering multiple together with the expandable side out and giving each its own source of inflation would allow for greater degrees of freedom, and chaining multiple clusters end to end would give it multiple joints. Better

actuation could also have been achieved with higher quality materials.

Fabrics with a larger contrast in elasticity would have allowed it to curl further, as well as a better match between the size of the fabric pocket and balloon. With these implementations, a control system would be vital to provide air to only the correct balloons at the correct time, possibly using a combination of solenoids and controls that allow instructions for different tasks that pressurize the correct ones depending on which task is performed.

- **The X-gripper** was a failure in our testing but has a great amount of potential. The actuator was prone to forming air bubbles and popping, as it's only as strong as its weakest point. Because of this, a more uniform fabrication method with more dense rubber would be vital to a successful gripper. A larger mold with proportionally wider channels could give the gripper the best chance of preventing a blockage in channels. It may help as well to use rubber of different densities for the two sides of it, with a more dense rubber being used on the side in direction of actuation. If the air channels were sectioned off from each other and controlled with multiple pumps the robot could grip objects in more complex ways. The x shaped gripper could be foregone completely for one that mimics a human hand, with multiple parallel digits and an opposing digit. This would use similar techniques to the X-gripper but in a completely different way, and is only one possible direction to take the design.
- **The SDM finger** arguably worked the best in its current configuration, and would benefit from a control system (possibly utilizing servos to reel in the

cords) similarly to the other end effectors. However, it could be drastically improved with a change in design. Multiple cords with controllable tension around a central axis would increase the range of motion of the finger. This assembly would in theory have the same range of motion as a ball and socket joint, like the human wrist. Alternatively, if the design was preserved and more fingers were used in concert in either a hand shaped or all opposed configuration, it would show increased dexterity and possibly strength over the other tested end effectors, as the design would be as strong as the failing point of the materials used. In fact, a recreation of the joints in the human body would be possible and likely a more realistic goal with a cable based design than one using air pressure.

There are many other methods by which soft robotic actuation occurs, and this project would benefit greatly from a more comprehensive dichotomy of types. Designs that deflate a balloon completely, making a vacuum around an object in shape of desired actuation are common in soft robotics and worth testing, as are dielectric materials that expand and contract when exposed to a current. Using similar methods to the tested ones but in a different way, pneumatic muscles use braided mesh material with a balloon inside. As the balloon expands outwards the mesh contracts in the direction along the cylindrical shape. This would require tests to be modified as the end effector wouldn't pick anything up in the same way but would be interesting to see.

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There are a wealth of options to expand upon the current projects including introducing new designs for testing and focusing more narrowly on one tested design.

Annotated Bibliography

“Knit Textile Bending Actuators.” Soft Robotics Toolkit, softroboticstoolkit.com/textile-actuators.

The fabrication and operation guide for the knit textile bending actuator. This page includes details and a step-by-step process for how to make each of the parts. Additionally, the page provides potential uses for the mechanism and cites other studies that highlight implementations of the design.

“SDM Fingers.” Soft Robotics Toolkit, softroboticstoolkit.com/book/sdm-fingers.

The main overview of the SDM finger end effector. This page provides sources to the fabrication and modeling of the SDM finger, including variations of the design and a guide to creating the mold. There is also a section that includes examples of testing the robot’s strength, which provided insight into prior testing of the design.

“Soft Gripper Fabrication Guide.” Soft Robotics Toolkit, softroboticstoolkit.com/resources-for-educators/soft-gripper.

The instructions for the fabrication of the X-gripper. This page includes a guide and supplemental video that details how to create an X-gripper. Also included is a parts list and budget, as well as expected time for fabrication.

B. Finio, "Air-Powered Soft Robotic Gripper," *Instructables*, 24-Oct-2017. [Online].

Available: <https://www.instructables.com/id/Air-Powered-Soft-Robotic-Gripper/>.

Additional implementations of the X-gripper design. This page highlights other potential designs that use a similar implementation of the X-gripper. Also included on this page is the process for the fabrication of the 3D printed molding used to cast the X-gripper, and a step by step process for pouring the silicon elastomer to form the end effector.

Appendices

Appendix A: Detailed Materials List

- Lulzbot Taz 5 3D Printer
- uArm Swift Pro Robotic Arm
 - Claw Gripper Attachment
 - Universal Gripper Attachment
 - Vacuum Gripper Attachment
- Dragon Skin 10 Fast Silicone Rubber
 - 4 lb
- PMC 780 Dry Silicone Rubber
 - 3 lb
- One Blood Pressure Cuff
 - Used for air pump
- Clear Vinyl Tubing, $\frac{1}{4}$ " O.D.
 - 10 ft
- Clear Vinyl Tubing, $\frac{3}{8}$ " O.D.
 - 10 ft
- Kevlar Cord
 - 10 ft
- One Hot Glue Gun
- Mini Glue Sticks, 12 Pack

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- For Glue Gun
- One Hand Application Glue Stick
- One Utility Knife
- One 1-Hole Punch
- One Awl
- A-Size Paper
 - 12 sheets
- One Pen
- Two Cardboard Boxes
 - Cardboard used for molding
- Plastic Cups, 16 oz
 - 21 Cups
- One Roll Electrical Tape
- One Roll Masking Tape
- One Roll Packing Tape
- One Pair Wire Cut/Strippers
- Wire, 14 ga
 - 10 ft
- Thermoplastic Elastomer Sheets
 - 1 Sq Yd
- One Tube Flexible Adhesive
- Spandex Fabric
 - 1 Sq Yd

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- One White Undershirt
 - Used for fabric pocket
- One Spool Thread
- One Sewing Needle
- One Pair Scissors
- One 12 mL Oral Curved Tip Syringe
- Hanging Masses
 - One 10 g
 - Two 20 g
 - One 50 g
 - One 100 g
 - Two 200 g
 - One 500 g
 - One 1000 g
- Three Eggs
- One Styrofoam Block
- One Wooden Block

Appendix B: Detailed Fabrication Instructions

Knit Textile Bending Actuator

1. Cut out actuator from template in Appendix G.
2. On stretchy spandex, trace out a 9" x 3" rectangle with the most stretchy orientation of the fabric in the length direction.
3. Trace actuator inside the rectangle
4. Cut out rectangle.
5. Place stretchy spandex rectangle on woven fabric of undershirt. Make sure that the template is either in the production direction (parallel to fibers) or perpendicular to it.
6. Cut around the perimeter to make two woven fabric rectangles
7. Two cut out rectangles
8. Set sewing machine to zig zag mode. Adjust the settings so that the stitch length is 2.0 and the pitch is 2.0
9. Hold the two fabric layers together and place them under the foot so the blunt end of the traced actuator shape is under the foot and the needle touches down slightly in from the perimeter. Back stitch for 2-3 stitches to lock thread in place.
10. Run the outline of the actuator through the machine with the zigzag stitch, keeping inside the actuator outline

11. Stop sewing when the machine gets back to the blunt edge of the actuator outline. Back stitch for 2-3 stitches to lock thread in place. Keep this end open and remove fabric from the machine.
12. Cut out template provided in Appendix H and trace on cardboard. Cut out traced template. Note, this step can be performed on any material with enough thickness to be able to feel when it is pressed up against the impulse sealer.
13. Take piece of thermoplastic elastomer (TPE) and fold it around template.
14. Impulse seal the exposed edge.
15. After impulse sealing, the exposed edge should look like this.
16. Impulse seal both angles at the tip of the template.
17. After impulse sealing, the tip should look like this.
18. Remove cardboard template and cut away excess material. Cut open the tip such that a tube can fit in the opening.
19. Insert tubing into opening at the tip such that 1-2 cm of tubing is sticking out.
20. Apply glue to exposed tube, push tube into the TPE opening and roll the plastic around the tube until it is sealed on all sides.
21. Invert balloon.
22. Impulse seal the open end.
23. Finished balloon.
24. Cut out the textile pocket, making sure not to get too close to the zigzag stitch.
25. Place the stick over the balloon and wrap the tip of the balloon around the stick. Insert the balloon using the stick into the fabric pocket. Once inserted, remove the stick without pulling the balloon out.

26. Sew the open end of the fabric pocket shut. Be careful not to puncture the balloon!

27. Inflate your newly constructed actuator!

SDM Finger

1. Cut out template in Appendix E. Trace onto cardboard and cut cardboard pieces out
2. Using hand application glue stick, glue paper template pieces onto cardboard backings. Cover them in clear packing tape.
3. Use glue gun to assemble pieces as per Appendix F Pictures. Use $\frac{1}{4}$ " O.D. tubing for the tubing. This will form the mold.
4. Prepare Dragon Skin silicone rubber (or similar) by mixing parts A and B as instructed in product directions (Appendix I for Dragon Skin). Mix approximately 6-8 fl oz.
5. Pour rubber into created mold, filling up to top.
6. Allow curing as instructed in product directions. (Note: It is advisable to add around 30% to the time indicated in instructions, to ensure proper drying.)
7. Break mold away from effector, making sure not to damage effector. (Note: Molds are not reusable, so the same care doesn't need to be taken for the mold.)
8. Thread kevlar cord through tubing to create finished end effector!

X-Gripper

1. Create and print X-gripper mold to specifications in Appendix D.
2. Prepare Dragon Skin silicone rubber (or similar) by mixing parts A and B as instructed in product directions (Appendix I for Dragon Skin). Mix approximately 4 fl oz.
3. Pour rubber into mold, completely filling it.
4. Pour leftover rubber into baking sheet, making a puddle larger than the X-gripper mold.
5. Agitate both pours until all air bubbles have been eliminated.
6. Allow curing as instructed in product directions. (Note: It is advisable to add around 30% to the time indicated in instructions, to ensure proper drying.)
7. Gently remove silicone rubber from mold, making sure channels have formed neatly.
8. Mix a smaller amount (approximately 2 fl oz) of Dragon Skin silicone rubber as per product directions.
9. Spread a very thin (around 1 mm) layer of new silicone rubber over the surface of the cured rubber in the baking sheet. The layer spread should be at least the size of the X-gripper. (Note: It is vital that this layer be thin so as not to obstruct the air channels.)
10. Place the cured rubber gripper (the one pulled up from the mold) on top of the new thin layer of uncured silicone rubber with the channel side facing down.

11. Apply the rest of the silicone rubber around the sides of the X-gripper to assist in making a seal air tight.
12. Allow rubber to cure.
13. Remove cured rubber from baking sheet.
14. Cut off excess rubber from puddle.
15. Optional: Allow rubber to sit under heat lamp for two hours to acclimate it to manipulation.
16. Insert pressurized air source into gripper via side between two appendages.
It is now ready to inflate.

Appendix C: JavaScript Source Code for uArm Swift Pro Testing

```

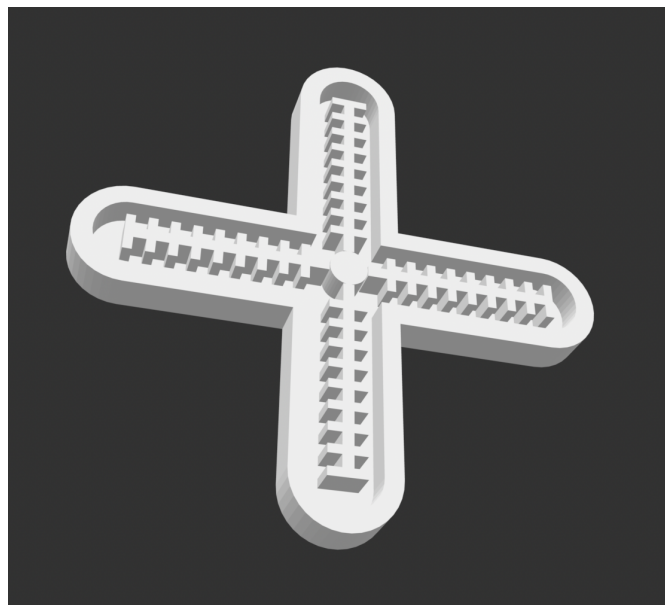
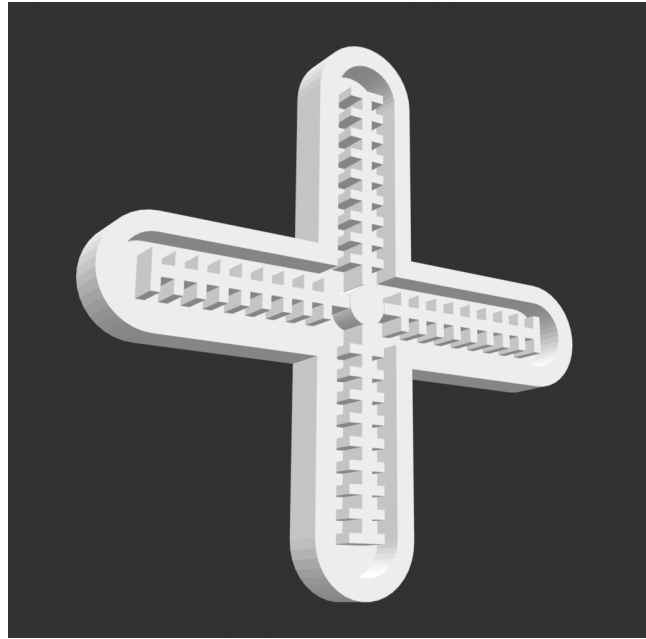
1  (async function () {
2      var x_axis, z_axis, original_z;
3
4
5      // Reset uArm to its home position.
6      await UArm.reset();
7      z_axis = 250;
8      UArm.set_speed(2);
9      await UArm.set_position({
10         "x": 200,
11         "y": 0,
12         "z": z_axis
13     });
14
15     BlocklyLib.KeyPressEvent.addEventListener(40, async function () {
16         // Let uArm move relatively in absolute coordinates.
17         await UArm.set_position({
18             "z": -5,
19             "relative": true
20         });
21         z_axis = (typeof z_axis == 'number' ? z_axis : 0) + -5.55;
22     });
23
24     BlocklyLib.KeyPressEvent.addEventListener(37, async function () {
25         // Let uArm move relatively in absolute coordinates.
26         await UArm.set_position({
27             "y": 10,
28             "relative": true
29         });
30     });
31
32     BlocklyLib.KeyPressEvent.addEventListener(39, async function () {
33         // Let uArm move relatively in absolute coordinates.
34         await UArm.set_position({
35             "y": -10,
36             "relative": true
37         });
38     });
39
40     BlocklyLib.KeyPressEvent.addEventListener(38, async function () {

```

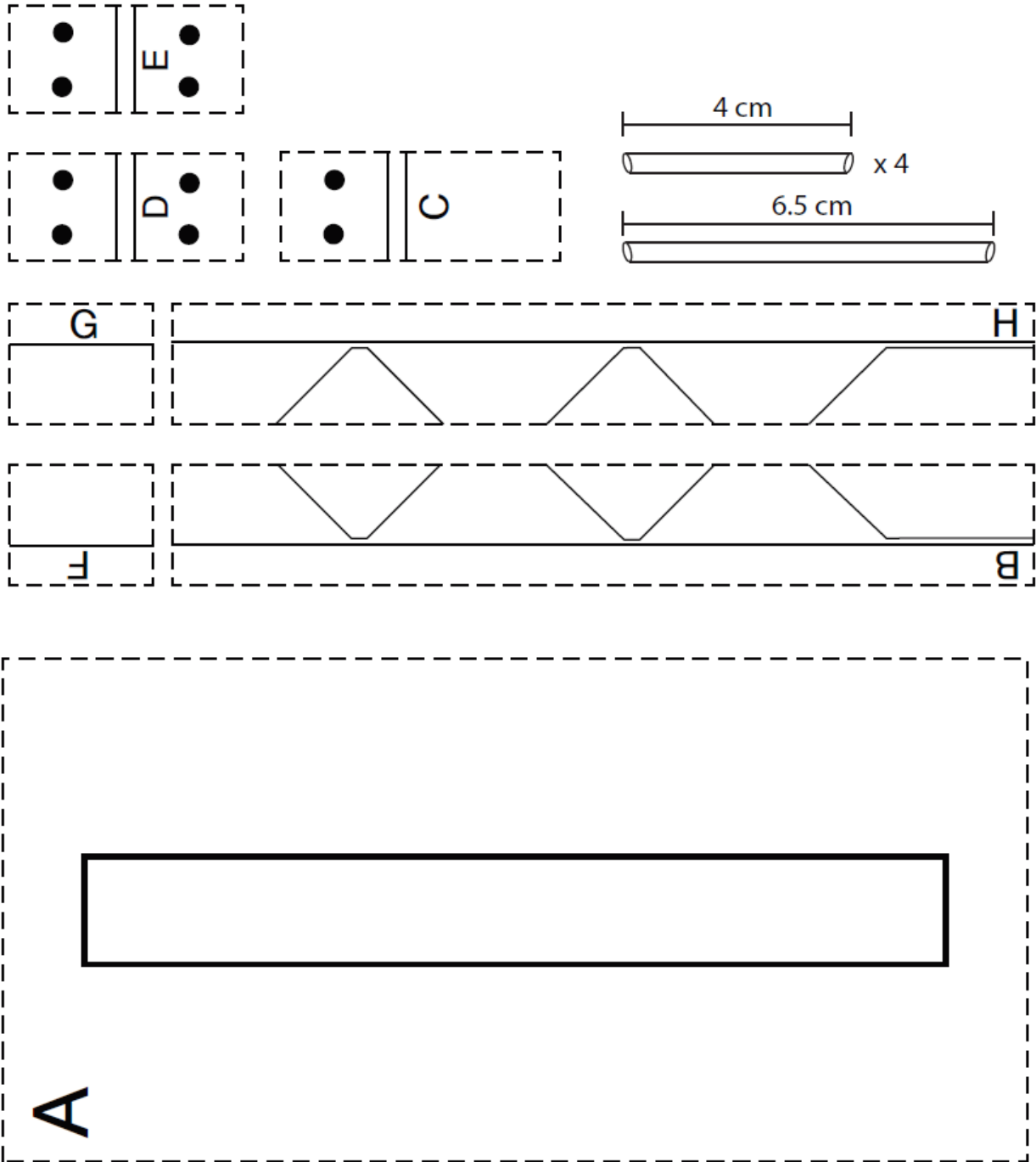
```
41 // Let uArm move relatively in absolute coordinates.
42 await UArm.set_position({
43   "z": 5,
44   "relative": true
45 });
46 z_axis = (typeof z_axis == 'number' ? z_axis : 0) + 5;
47 });
48
49 // This command let you trigger commands by pressing
50 // the suction cup (which is also a switch) of uArm.
51 UArm.TipSensor.addEventListener({
52   "callback": async function () {
53     await UArm.set_buzzer({
54       "frequency": 261.63,
55       "duration": 0.1,
56       "wait": true
57     });
58     await UArm.set_buzzer({
59       "frequency": 523.25,
60       "duration": 0.1,
61       "wait": true
62     });
63   }
64 });
65
66 BlocklyLib.KeyPressEvent.addEventListener(32, async function () {
67   await UArm.set_pump({
68     "ON": true,
69     "wait": true
70   });
71   await UArm.set_position({
72     "x": 200,
73     "y": 0,
74     "z": 250
75   });
76   await UArm.wait(1);
77   await UArm.set_buzzer({
78     "frequency": 261.63,
79     "duration": 0.1,
80     "wait": true
```

```
81     });
82     await UArm.wait(1);
83     await UArm.set_buzzer({
84         "frequency": 261.63,
85         "duration": 0.1,
86         "wait": true
87     });
88     await UArm.wait(1);
89     await UArm.set_buzzer({
90         "frequency": 523.25,
91         "duration": 0.1,
92         "wait": true
93     });
94     await UArm.set_position({
95         "x": 200,
96         "y": 0,
97         "z": z_axis
98     });
99     await UArm.set_pump({
100         "ON": false,
101         "wait": true
102     });
103     z_axis = 250;
104     await UArm.set_position({
105         "x": 200,
106         "y": 0,
107         "z": z_axis
108     });
109 });
110 }());
```

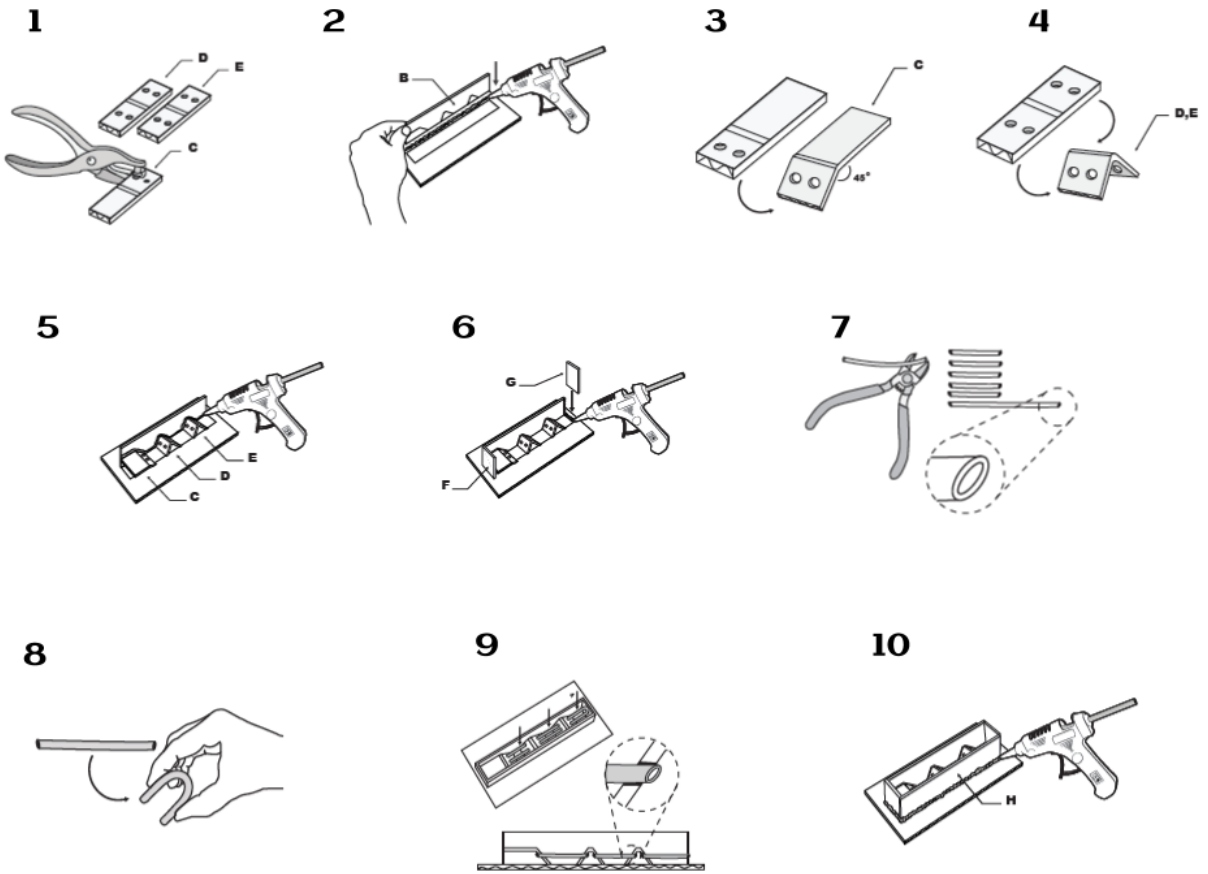
Appendix D: X-Gripper Solidworks Drawing



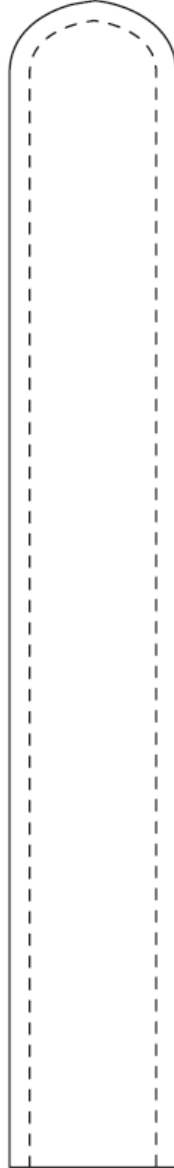
Appendix E: SDM Finger Template



Appendix F: SDM Finger Assembly Pictograph



Appendix G: Knit Textile Bending Actuator Fabric Template



Appendix H: Knit Textile Bending Actuator Balloon Template



Appendix I: Smooth-On Dragon Skin 10 Fast Information

The attached document contains information on the silicone rubber used in the project, as well as its SDS data sheet.

Dragon Skin™ Series

Addition Cure Silicone Rubber Compounds



Cured Material Certified Skin Safe! www.smooth-on.com

PRODUCT OVERVIEW

Dragon Skin™ silicones are high performance platinum cure liquid silicone compounds that are used for a variety of applications ranging from creating skin effects and other movie special effects to making production molds for casting a variety of materials. Because of the superior physical properties and flexibility of Dragon Skin™ rubbers, they are also used for medical prosthetics and cushioning applications. Dragon Skin™ rubbers are also used for a variety of industrial applications and have a service temperature range of a constant -65°F to +450°F (-53°C to +232°C).

Great for Making Molds for a Variety of Applications - Available in Shore 10A, 20A and 30A, Dragon Skin™ silicones can be used to make exceptionally strong and tear resistant molds for casting plaster, wax, concrete (limited production run), resins and other materials.

Time Tested, Versatile Special Effects Material - Soft, super-strong and stretchy, Dragon Skin™ 10 (Very Fast, Fast, Medium and Slow speeds) is used around the world to make spectacular skin and creature effects. An infinite number of color effects can be achieved by adding Silc Pig™ silicone pigments or Cast Magic™ effects powders. Cured rubber can also be painted with the Psycho Paint™ system. Cured material is skin safe and certified by an independent laboratory to ISO 10993-10, Biological evaluation of medical devices, Part 10: Tests for irritation and skin sensitization.

Easy To Use - Dragon Skin™ silicones are mixed 1A:1B by weight or volume. Liquid rubber can be thinned with Silicone Thinner™ or thickened with THI-VEX™. Rubber cures at room temperature (73°F/23°C) with negligible shrinkage. *Vacuum degassing is recommended to minimize air bubbles in cured rubber.*

TECHNICAL OVERVIEW

	Mixed Viscosity (ASTM D-2393)	Specific Gravity (g/cc) (ASTM D-1475)	Specific Volume (cu. in./lb.) (ASTM D-1475)	Pot Life (ASTM D-2471)	Cure Time	Shore A Hardness (ASTM D-2240)	Tensile Strength (ASTM D-412)	100% Modulus (ASTM D-412)	Elongation at Break % (ASTM D-412)	Die B Tear Strength (ASTM D-624)	Shrinkage (in./in.) (ASTM D-2566)
Dragon Skin™ 10 Very Fast	23,000 cps	1.07	25.8	4 min.	30 min.	10A	475 psi	22 psi	1000%	102 pli	< .001 in./in.
Dragon Skin™ 10 Fast	23,000 cps	1.07	25.8	8 min.	75 min.	10A	475 psi	22 psi	1000%	102 pli	< .001 in./in.
Dragon Skin™ 10 Medium	23,000 cps	1.07	25.8	20 min.	5 hours	10A	475 psi	22 psi	1000%	102 pli	< .001 in./in.
Dragon Skin™ 10 Slow	23,000 cps	1.07	25.8	45 min.	7 hours	10A	475 psi	22 psi	1000%	102 pli	< .001 in./in.
Dragon Skin™ 20	20,000 cps	1.08	25.6	25 min.	4 hours	20A	550 psi	49 psi	620%	120 pli	< .001 in./in.
Dragon Skin™ 30	30,000 cps	1.08	25.7	45 min.	16 hours	30A	500 psi	86 psi	364%	108 pli	< .001 in./in.

Mix Ratio: 1A:1B by volume or weight
Color: Translucent

Useful Temperature Range: -65°F to +450°F (-53°C to +232°C)
Dielectric Strength (ASTM D-147-97a): >350 volts/mil

*All values measured after 7 days at 73°F/23°C

PROCESSING RECOMMENDATIONS

PREPARATION... Safety - Use in a properly ventilated area ("room size" ventilation). Wear safety glasses, long sleeves and rubber gloves to minimize contamination risk. Wear vinyl gloves only. Latex gloves will inhibit the cure of the rubber.

Store and use material at room temperature (73°F/23°C). Warmer temperatures will drastically reduce working time and cure time. Storing material at warmer temperatures will also reduce the usable shelf life of unused material. These products have a limited shelf life and should be used as soon as possible. Mixing containers should have straight sides and a flat bottom. Mixing sticks should be flat and stiff with defined edges for scraping the sides and bottom of your mixing container.

Cure Inhibition - Addition-cure silicone rubber may be inhibited by certain contaminants in or on the pattern to be molded resulting in tackiness at the pattern interface or a total lack of cure throughout the mold. Latex, tin-cure silicone, sulfur clays, certain wood surfaces, newly cast polyester, epoxy, tin cure silicone rubber or urethane rubber may cause inhibition. If compatibility between the rubber and the surface is a concern, a small-scale test is recommended. Apply a small amount of rubber onto a non-critical area of the pattern. Inhibition has occurred if the rubber is gummy or uncured after the recommended cure time has passed.

Because no two applications are quite the same, a small test application to determine suitability for your project is recommended if performance of this material is in question.

Safety First!

The Material Safety Data Sheet (MSDS) for this or any Smooth-On product should be read prior to use and is available upon request from Smooth-On. All Smooth-On products are safe to use if directions are read and followed carefully.

Keep Out of Reach of Children

Be careful. Use only with adequate ventilation. Contact with skin and eyes may cause irritation. Flush eyes with water for 15 minutes and seek immediate medical attention. Remove from skin with waterless hand cleaner followed by soap and water.

Important: The information contained in this bulletin is considered accurate. However, no warranty is expressed or implied regarding the accuracy of the data, the results to be obtained from the use thereof, or that any such use will not infringe upon a patent. User shall determine the suitability of the product for the intended application and assume all risk and liability whatsoever in connection therewith.

Cure Inhibition - To prevent inhibition, one or more coatings of a clear acrylic lacquer applied to the model surface is usually effective. Allow any sealer to thoroughly dry before applying rubber. Note: Even with a sealer, platinum silicones will not work with modeling clays containing heavy amounts of sulfur. Do a small scale test for compatibility before using on your project.

Applying A Release Agent - Although not usually necessary, a release agent make demolding easier when pouring into or over most surfaces. Ease Release™ 200 is a proven release agent for making molds with silicone rubber. Mann Ease Release™ products are available from Smooth-On or your Smooth-On distributor.

IMPORTANT: To ensure thorough coverage, lightly brush the release agent with a soft brush over all surfaces of the model. Follow with a light mist coating and let the release agent dry for 30 minutes.

If there is any question about the effectiveness of a sealer/release agent combination, a small-scale test should be made on an identical surface for trial.

MEASURING & MIXING...

Stir Part A and Part B thoroughly before dispensing. After dispensing required amounts of Parts A and B into mixing container (1A:1B by volume or weight), **mix thoroughly for 3 minutes making sure that you scrape the sides and bottom of the mixing container several times.** After mixing parts A and B, vacuum degassing is recommended to eliminate any entrapped air. Vacuum material for 2-3 minutes (29 inches of mercury), making sure that you leave enough room in container for product volume expansion.

POURING, CURING & MOLD PERFORMANCE...

For best results, pour your mixture in a single spot at the lowest point of the containment field. Let the rubber seek its level up and over the model. **A uniform flow will help minimize entrapped air.** The liquid rubber should level off at least 1/2" (1.3 cm) over the highest point of the model surface.

Curing / Post Curing - Allow rubber to cure as prescribed at room temperature (73°F/23°C) before demolding. Do not cure rubber where temperature is less than 65°F/18°C. **Optional:** Post curing the mold will aid in quickly attaining maximum physical and performance properties. After curing at room temperature, expose the rubber to 176°F/80°C for 2 hours and 212°F/100°C for one hour. Allow mold to cool to room temperature before using.

If Using As A Mold - When first cast, silicone rubber molds exhibit natural release characteristics. Depending on what is being cast into the mold, mold lubricity may be depleted over time and parts will begin to stick. No release agent is necessary when casting wax or gypsum. Applying a release agent such as Ease Release™ 200 (available from Smooth-On) prior to casting polyurethane, polyester and epoxy resins is recommended to prevent mold degradation.

Thickening Dragon Skin™ Silicones - THI-VEX™ is made especially for thickening Smooth-On's silicones for vertical surface application (making brush-on molds). Different viscosities can be attained by varying the amount of THI-VEX™. See the **THI-VEX™ technical bulletin** (available from Smooth-On or your Smooth-On distributor) for full details.

Thinning Dragon Skin™ Silicones - Smooth-On's **Silicone Thinner™** will lower the viscosity of Dragon Skin™ for easier pouring and vacuum degassing. **A disadvantage** is that ultimate tear and tensile are reduced in proportion to the amount of **Silicone Thinner™** added. **It is not recommended to exceed 10% by weight of total system (A+B).** See the **Silicone Thinner™ technical bulletin** (available from Smooth-On or your Smooth-On distributor) for full details.

Mold Performance & Storage - The physical life of the mold depends on how you use it (materials cast, frequency, etc.). Casting abrasive materials such as concrete can quickly erode mold detail, while casting non-abrasive materials (wax) will not affect mold detail. Before storing, the mold should be cleaned with a soap solution and wiped fully dry. Two part (or more) molds should be assembled. Molds should be stored on a level surface in a cool, dry environment.



Call Us Anytime With Questions About Your Application.

Toll-free: (800) 381-1733 Fax: (610) 252-6200

The new www.smooth-on.com is loaded with information about mold making, casting and more.



Safety Data Sheet

GHS Compliant

SDS No. 823A

Section 1 - Identification

1.1 Product Identifier: Part A for: Body Double® & Body Double® SILK; Dragon Skin® Series & F/X Pro; Ecoflex® Series & Gel; Encapso® K; Equinox® Series; EZ Brush® Silicone; EZ-Spray® Silicone Series; Mold Max® Series; Mold Star® Series; OOMO® Series; PoYo® Putty 40; Psycho Paint®; Rebound® Series; Rubber Glass®, Silicone 1515; Silicone 1603; Silicone 3030; Skin Tite®; Smooth-Sil® Series; Solaris®; SomaFoama® Series; SORTA-Clear® Series; Silicone 1708

1.2 General Use: Silicone Elastomer

1.3 Manufacturer: Smooth-On, Inc.,
5600 Lower Macungie Rd., Macungie, PA 18062
Phone (610) 252-5800, FAX (610) 252-6200
SDS@Smooth-On.com

1.4 Emergency Contact: Chem-Tel
Domestic: 800-255-3924 International: 813-248-0585

Section 2 - Hazard(s) Identification

2.1 Classification of the substance or mixture

Not a hazardous substance or mixture according to United States Occupational Safety and Health Administration (OSHA) Hazard Communication Standard (29 CFR 1910.1200), the Canadian Workplace Hazardous Materials Information System (WHMIS) and Regulation (EC) No 1272/2008 and subsequent amendments.

2.2 GHS Label elements, including precautionary statements

Pictogram(s): none

Signal word: none

General Precautions:

P101: If medical advice is needed, have product container or label at hand.

P102: Keep out of reach of children.

P103: Read label before use.

Hazards not otherwise classified (HNOC) or not covered by GHS - none

Section 3 - Composition / Information on Ingredients

3.1 Substances

No ingredients are hazardous according to Regulation 2012 OSHA Hazard Communication Standard 29 CFR 1910.1200 criteria.

Section 4 - First Aid Measures

4.1 Description of first aid measures

Inhalation: Remove source(s) of contamination and move victim to fresh air. If breathing has stopped, give artificial respiration, then oxygen if needed. Contact physician immediately.

Eye Contact: Flush eyes with plenty of water. If irritation persists, seek medical attention.


Skin Contact: In case of skin contact, wash thoroughly with soap and water.

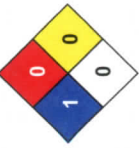
Ingestion: Do not induce vomiting unless instructed by a physician. Never give anything by mouth to an unconscious person.

4.2 Most important symptoms and effects, both acute and delayed
None known.

4.3 After first aid, get appropriate in-plant, paramedic, or community medical support.

<p align="center">Section 5 - Fire-Fighting Measures</p> <p>5.1 Extinguishing Media: Water Fog, Dry Chemical, and Carbon Dioxide Foam</p> <p>5.2 Special hazards arising from the substance or mixture: None known.</p> <p>5.3 Advice for firefighters: Use water spray to cool fire-exposed surfaces and to protect personnel. Shut off "fuel" to fire. If a leak or spill has not ignited, use water spray to disperse the vapors. Either allow fire to burn under controlled conditions or extinguish with foam or dry chemical. Try to cover liquid spills with foam. Because fire may produce toxic thermal decomposition products, wear a self-contained breathing apparatus (SCBA) with a full face piece operated in pressure demand or positive-pressure mode.</p>	<p align="center">Section 6 - Accidental Release Measures</p> <p>6.1 Personal precautions, protective equipment and emergency procedures: Only properly protected personnel should remain in the spill area, dike and contain spill. Stop or reduce discharge if it can be done safely.</p> <p>6.2 Environmental precautions: No special environmental precautions required.</p> <p>6.3 Methods and material for containment and cleaning up: absorb or scrape up excess into suitable container for disposal; wash area with dilute ammonia solution</p> <p>6.4 Reference to other sections: if appropriate Sections 8 and 13 shall be referred to.</p>	<p align="center">Section 7 - Handling and Storage</p> <p>7.1 Precautions for safe handling: Use good general housekeeping procedures. Wash hands after use.</p> <p>7.2 Conditions for safe storage, including any incompatibilities: Keep container(s) tightly closed and properly labeled. Store in cool, dry, well ventilated place away from heat, direct sunlight, strong oxidizers and any incompatibles. Store in approved containers and protect against physical damage. Keep containers securely sealed when not in use. Indoor storage should meet OSHA standards and appropriate fire codes. Containers that have been opened must be carefully resealed to prevent leakage. Empty containers retain residue and may be dangerous. Avoid water contamination.</p> <p>7.3 Specific end use(s): These precautions are for room temperature handling. Other uses including elevated temperatures or aerosol/spray applications may require added precautions.</p>	<p align="center">Section 8 - Exposure Controls / Personal Protection</p> <p>8.1 Control parameters: none defined</p> <p>8.2 Exposure controls:</p> <p>Respiratory Protection: Should a respirator be needed, follow OSHA respirator regulations 29 CFR 1910.134 and European Standards EN 141, 143 and 371; wear an MSHA/NIOSH or European Standards EN 141, 143 and 371 approved respirators equipped with organic vapor cartridges.</p> <p>Hand Protection: Wear any liquid-tight gloves such as butyl rubber, neoprene or PVC.</p> <p>Eye Protection: Safety glasses with side shields per OSHA eye- and face-protection regulations 29 CFR 1910.133 and European Standard EN166. Contact lenses are not eye protective devices. Appropriate eye protection must be worn instead of, or in conjunction with contact lenses.</p> <p>Other Protective Clothing/Equipment: Additional protective clothing or equipment is not normally required. Provide eye bath and safety shower.</p> <p>Comments: Never eat, drink, or smoke in work areas. Practice good personal hygiene after using this material, especially before eating, drinking, smoking, using the toilet, or applying cosmetics. Wash thoroughly after handling.</p>
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<p>Section 13 - Disposal Considerations</p> <p>13.1 Waste treatment methods: Under RCRA it is the responsibility of the user of the product to determine at the time of disposal whether the product meets RCRA criteria for hazardous waste. Waste management should be in full compliance with federal, state and local laws. Empty containers retain product residue which may exhibit hazards of material, therefore to not pressurize, cut, glaze, weld or use for any other purposes. Return drums to reclamation centers for proper cleaning and reuse.</p>	<p>Section 14 - Transport Information</p> <p>Not regulated by DOT, IATA or IMDG</p> <p>14.1 UN number: none</p> <p>14.2 UN proper shipping name: none</p> <p>14.3 Transport hazard class(es): not applicable</p> <p>14.4 Packing group: not applicable</p> <p>14.5 Environmental hazards: none known</p> <p>14.6 Special precautions for user: none known</p> <p>14.7 Transport in bulk according to Annex II of MARPOL73/78 and the IBC Code: not applicable</p>	<p>Section 15 - Regulatory Information</p> <p>15.1 Safety health and environmental regulations/legislation specific for the substance or mixture:</p> <p>In the United States (EPA Regulations):</p> <p>TSCA Inventory Status (40 CFR710): All components of this formulation are listed in the TSCA Inventory.</p> <p>SARA 302 Components: No chemicals in this material are subject to the reporting requirements of SARA Title III, Section 302.</p> <p>SARA 313 Components: No chemicals in this material are subject to the reporting requirements of SARA Title III, Section 313.</p> <p>SARA 311/312 Hazards: none</p> <p>California Proposition 65: This product does not intentionally contain any chemicals known to the state of California to cause cancer, birth defects or other reproductive harm.</p> <p>15.2 Chemical safety assessment: No chemical safety assessment has been carried out for this substance/mixture by the supplier.</p>	<p>16 - Other Information</p> <div style="display: flex; justify-content: space-around;"> <table border="1" style="border-collapse: collapse;"> <tr><td style="padding: 2px;">HMIS</td></tr> <tr><td style="padding: 2px;">H 1</td></tr> <tr><td style="padding: 2px;">F 0</td></tr> <tr><td style="padding: 2px;">R 0</td></tr> </table>  </div> <p>Revision: 7 Date Prepared: March 2, 2017</p> <p style="text-align: right;">NFPA</p>	HMIS	H 1	F 0	R 0
HMIS							
H 1							
F 0							
R 0							

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F 0							
R 0							

<p>Section 9 - Physical and Chemical Properties</p> <p>9.1 Information on basic physical and chemical properties: Appearance : viscous liquid Odor/Threshold: Mild to sweet odor pH: N.A. (non-aqueous) Melting Point/Freezing Point: N.A. Low/High Boiling Point: N.A. Flash Point: >300 °F Evaporation Rate: Not available Flammability: f.p. at or above 200 °F UEL/LEL: Not available</p>	<p>Section 10 - Stability and Reactivity</p> <p>10.1 Reactivity: No hazardous reactions if stored and handled as prescribed/indicated., No corrosive effect on metal. Not fire propagating. 10.2 Chemical stability: These products are stable at room temperature in closed containers under normal storage and handling conditions. 10.3 Possibility of hazardous reactions: Hazardous polymerization cannot occur. 10.4 Conditions to avoid: none known 10.5 Incompatible materials: strong bases and acids 10.6 Hazardous decomposition products: Thermal oxidative decomposition can produce carbon oxides, gasses/vapors, and traces of incompletely burned carbon compounds.</p>	<p>Section 11- Toxicological Information</p> <p>11.1 Information on toxicological effects: Skin Corrosion/Irritation: no data Serious Eye Damage/Irritation: no data Respiratory/Skin Sensitization: no data Germ Cell Mutagenicity: no data Carcinogenicity: No component of these products present at levels greater than or equal to 0.1% is identified as a carcinogen or potential carcinogen by IARC, ACGIH or NTP. Reproductive Toxicity: no data Specific Target Organ Toxicity – Single Exposure: no data Specific Target Organ Toxicity – Repeated Exposure: no data Aspiration Hazard: no data Acute Toxicity: no data Chronic Exposure: no data Potential Health Effects – Miscellaneous: no data</p>	<p>Section 12 - Ecological Information</p> <p>12.1 Toxicity: no data 12.2 Persistence and Degradability: no data 12.3 Bioaccumulative Potential: no data 12.4 Mobility in Soil: no data 12.5 Results of PBT and vPvB assessment: no data 12.6 Other Adverse Effects: no data</p>
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Glossary: ACGIH-American Conference of Governmental Industrial Hygienists; ANSI-American National Standards Institute; Canadian TDG-Canadian Transportation of Dangerous Goods; CAS-Chemical Abstract Service; Chemtrec-Chemical Transportation Emergency Center (US); CHIP-Chemical Hazard Information and Packaging; DSL-Domestic Substances List; EC-Equivalent Concentration; EH40 (UK)-HSE Guidance Note EH40 Occupational Exposure Limits; EPCRA-Emergency Planning and Community Right-To-Know Act; ESL-Effects screening levels; GHS-Globally Harmonized System of Classification and Labelling of Chemicals; HMIS-Hazardous Material Information Service; IATA-International Air Transport Association; IMDG-International Maritime Dangerous Goods Code; LC-Lethal Concentration; LD-Lethal Dose; LEL-Lower Explosion Level; NFPA-National Fire Protection Association; OEL-Occupational Exposure Limit; OSHA-Occupational Safety and Health Administration, US Dept. of Labor; PEL-Permissible Exposure Limit; SARA (Title III)-Superfund Amendments and Reauthorization Act; SARA 313-Superfund Amendments and Reauthorization Act, Section 313; SCBA-Self-Contained Breathing Apparatus; STEL-Short Term Exposure Limit; TCEQ-Texas Commission on Environmental Quality; TLV-Threshold Limit Value; TSCA-Toxic Substances Control Act Public Law 94-469; TWA-Time Weighted Value; UEL-Upper Explosion Level; US DOT-US Department of Transportation; WHMIS-Workplace Hazardous Materials Information System.

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This SDS is prepared to comply with the Globally Harmonized System of Classification and Labelling of Chemicals (GHS) as prescribed by the United States (US) Occupational Safety and Health Administration (OSHA) Hazard Communication Standard (29 CFR 1910.1200), the Canadian Workplace Hazardous Materials Information System (WHMIS), and European Union Regulation (EC) No 1907/2006 of the European Parliament and of the Council of 18 December 2006 (REACH).

Classifications of the chemical in accordance with 29 CFR 1910.1200, signal word, hazard and precautionary statement(s), symbol(s) and other information are based on listed concentration of each hazardous ingredient. Unlisted ingredients are not "hazardous" per the OSHA Hazard Communication Standard (29 CFR 1910.1200), WHMIS and EC No 1907/2006 and are considered trade secrets under US Federal Law (29 CFR and 40 CFR), Canadian Law (Health Canada Legislation), and European Union Directives.



Safety Data Sheet

GHS Compliant

SDS No. 823B

<p>Section 1 - Identification</p> <p>1.1 Product Identifier: Part B for: Body Double® & Body Double® SILK; Dragon Skin® Series & F/X Pro; Ecoflex® Series & Gel; Encaps® K; Equinox® Series; EZ Brush® Silicone; EZ-Spray® Silicone Series; Psycho Paint®; Mold Star® Series; OMOO® Series; Rebound® Series; Rubber Glass®; Skin Tite®; Smooth-Sil® Series; Soma Foama® 15 and 25; Solaris®; SORTA-Clear® Series; Silicone 1603; Silicone 1708</p> <p>1.2 General Use: Silicone Elastomer Crosslinker</p> <p>1.3 Manufacturer: Smooth-On, Inc., 5600 Lower Macungie Rd., Macungie, PA 18062 Phone (610) 252-5800, FAX (610) 252-6200 SDS@Smooth-On.com</p> <p>Emergency Contact: Chem-Tel Domestic: 800-255-3924 International: 813-248-0585</p>	<p>Section 2 - Hazard(s) Identification</p> <p>2.1 Classification of the substance or mixture Not a hazardous substance or mixture according to United States Occupational Safety and Health Administration (OSHA) Hazard Communication Standard (29 CFR 1910.1200), the Canadian Workplace Hazardous Materials Information System (WHMIS) and Regulation (EC) No 1272/2008 and subsequent amendments.</p> <p>2.2 GHS Label elements, including precautionary statements Pictogram(s): none Signal word: none General Precautions: P101: If medical advice is needed, have product container or label at hand. P102: Keep out of reach of children. P103: Read label before use.</p> <p>Hazards not otherwise classified (HNOC) or not covered by GHS - none</p>	<p>Section 3 - Composition / Information on Ingredients</p> <p>3.1 Substances No ingredients are hazardous according to Regulation 2012 OSHA Hazard Communication Standard 29 CFR 1910.1200 criteria.</p>	<p>Section 4 - First Aid Measures</p> <p>4.1 Description of first aid measures Inhalation: Remove source(s) of contamination and move victim to fresh air. If breathing has stopped, give artificial respiration, then oxygen if needed. Contact physician immediately. Eye Contact: Flush eyes with plenty of water. If irritation persists, seek medical attention. Skin Contact: In case of skin contact, wash thoroughly with soap and water. Ingestion: Do not induce vomiting unless instructed by a physician. Never give anything by mouth to an unconscious person. 4.2 Most important symptoms and effects, both acute and delayed None known. 4.3 After first aid, get appropriate in-plant, paramedic, or community medical support.</p>
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Section 5 - Fire-Fighting Measures

- 5.1 **Extinguishing Media:** Water Fog, Dry Chemical, and Carbon Dioxide Foam
- 5.2 **Special hazards arising from the substance or mixture:** None known.
- 5.3 **Advice for firefighters:** Use water spray to cool fire-exposed surfaces and to protect personnel. Shut off "fuel" to fire. If a leak or spill has not ignited, use water spray to disperse the vapors. Either allow fire to burn under controlled conditions or extinguish with foam or dry chemical. Try to cover liquid spills with foam. Because fire may produce toxic thermal decomposition products, wear a self-contained breathing apparatus (SCBA) with a full face piece operated in pressure demand or positive-pressure mode.

Section 6 - Accidental Release Measures

- 6.1 **Personal precautions, protective equipment and emergency procedures:** Only properly protected personnel should remain in the spill area; dike and contain spill. Stop or reduce discharge if it can be done safely.
- 6.2 **Environmental precautions:** No special environmental precautions required.
- 6.3 **Methods and material for containment and cleaning up:** absorb or scrape up excess into suitable container for disposal; wash area with dilute ammonia solution
- 6.4 **Reference to other sections:** if appropriate Sections 8 and 13 shall be referred to.

Section 7 - Handling and Storage

- 7.1 **Precautions for safe handling:** Use good general housekeeping procedures. Wash hands after use.
- 7.2 **Conditions for safe storage, including any incompatibilities:** Keep container(s) tightly closed and properly labeled. Store in cool, dry, well ventilated place away from heat, direct sunlight, strong oxidizers and any incompatibles. Store in approved containers and protect against physical damage. Keep containers securely sealed when not in use. Indoor storage should meet OSHA standards and appropriate fire codes. Containers that have been opened must be carefully resealed to prevent leakage. Empty containers retain residue and may be dangerous. Avoid water contamination.
- 7.3 **Specific end use(s):** These precautions are for room temperature handling. Other uses including elevated temperatures or aerosol/spray applications may require added precautions.

Section 8 - Exposure Controls / Personal Protection

- 8.1 **Control parameters:** none defined
- 8.2 **Exposure controls:**

Respiratory Protection: Should a respirator be needed, follow OSHA respirator regulations 29 CFR 1910.134 and European Standards EN 141, 143 and 371; wear an MSHA/NIOSH or European Standards EN 141, 143 and 371 approved respirators equipped with organic vapor cartridges.

Hand Protection: Wear any liquid-tight gloves such as butyl rubber, neoprene or PVC.

Eye Protection: Safety glasses with side shields per OSHA eye- and face-protection regulations 29 CFR 1910.133 and European Standard EN166. Contact lenses are not eye protective devices. Appropriate eye protection must be worn instead of, or in conjunction with contact lenses.

Other Protective Clothing/Equipment: Additional protective clothing or equipment is not normally required. Provide eye bath and safety shower.

Comments: Never eat, drink, or smoke in work areas. Practice good personal hygiene after using this material, especially before eating, drinking, smoking, using the toilet, or applying cosmetics. Wash thoroughly after handling.

Glossary: ACGIH-American Conference of Governmental Industrial Hygienists; ANSI-American National Standards Institute; Canadian TDG-Canadian Transportation of Dangerous Goods; CAS-Chemical Abstract Service; Chemtrec-Chemical Transportation Emergency Center (US); CHIP-Chemical Hazard Information and Packaging; DSL-Domestic Substances List; EC-Equivalent Concentration; EH40 (UK)-HSE Guidance Note EH40 Occupational Exposure Limits; EPCRA-Emergency Planning and Community Right-To-Know Act; ESL-Effects screening levels; GHS-Globally Harmonized System of Classification and Labelling of Chemicals; HMIS-Hazardous Material Information Service; IATA-International Air Transport Association; IMDG-International Maritime Dangerous Goods Code; LC-Lethal Concentration; LD-Lethal Dose; LEL-Lower Explosion Level; NFPA-National Fire Protection Association; OEL-Occupational Exposure Limit; OSHA-Occupational Safety and Health Administration, US Dept. of Labor; PEL-Permissible Exposure Limit; SARA (Title III)-Superfund Amendments and Reauthorization Act; SARA 313-Superfund Amendments and Reauthorization Act, Section 313; SCBA-Self-Contained Breathing Apparatus; STEL-Short Term Exposure Limit; TCEQ-Texas Commission on Environmental Quality; TLV-Threshold Limit Value; TSCA-Toxic Substances Control Act Public Law 94-469; TWA-Time Weighted Value; UEL-Upper Explosion Level; US DOT-US Department of Transportation; WHMIS-Workplace Hazardous Materials Information System.

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Section 9 - Physical and Chemical Properties

9.1 Information on basic physical and chemical properties:

Appearance : viscous liquid
Vapor Pressure: None (Polymeric Resin)
Vapor Density (Air=1): >1
Specific Gravity (H₂O=1, at 4 °C): 1.05-1.15
pH: N.A. (non-aqueous)
Water Solubility: Insoluble
Partition coefficient: Not available
Auto-ignition temperature: Not available
Decomposition temperature: Not available
Viscosity: 5,000 – 50,000 centipoise
% Volatile: Nil

Section 10 - Stability and Reactivity

10.1 Reactivity: No hazardous reactions if stored and handled as prescribed/indicated., No corrosive effect on metal. Not fire propagating.
10.2 Chemical stability: These products are stable at room temperature in closed containers under normal storage and handling conditions.
10.3 Possibility of hazardous reactions: Hazardous polymerization cannot occur.
10.4 Conditions to avoid: none known
10.5 Incompatible materials: strong bases and acids
10.6 Hazardous decomposition products: Thermal oxidative decomposition can produce carbon oxides, gasses/vapors, and traces of incompletely burned carbon compounds.

Section 11 - Toxicological Information

11.1 Information on toxicological effects:
Skin Corrosion/Irritation: no data
Serious Eye Damage/Irritation: no data
Respiratory/Skin Sensitization: no data
Germ Cell Mutagenicity: no data
Carcinogenicity: No component of these products present at levels greater than or equal to 0.1% is identified as a carcinogen or potential carcinogen by IARC, ACGIH or NTP.
Reproductive Toxicity: no data
Specific Target Organ Toxicity – Single Exposure: no data
Specific Target Organ Toxicity – Repeated Exposure: no data
Aspiration Hazard: no data
Acute Toxicity: no data
Chronic Exposure: no data
Potential Health Effects – Miscellaneous: no data

Section 12 - Ecological Information

12.1 Toxicity: no data
12.2 Persistence and Degradability: no data
12.3 Bioaccumulative Potential: no data
12.4 Mobility in Soil: no data
12.5 Results of PBT and vPvB assessment: no data
12.6 Other Adverse Effects: no data