How to Mould, Bond, and Seal Soft Silicone: Practical Solutions to Common Problems

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Abstract— **Improved access to advanced manufacturing techniques, such as additive manufacturing, has caused soft robotic research to increase in popularity over recent years. However, even with growing possibilities, manufacturing experience, and research in soft robotics, problems within manufacturing persist that require solving. The problems encountered can take various forms, from silicone inhibition in resin-printed moulds to adhering silicone to rigid components and designing pressure inlets that withstand higher pressures. However, the solutions are not always documented, preventing other researchers from using the findings to help them innovate in the field. In this context, we present solutions to the aforementioned manufacturing problems that are encountered within soft robotics. We present a post-processing method to allow SLA/DLP printed components to be used as silicone moulds without causing silicone inhibition. We show a method to bond silicone to 3D-printed rigid structures through lattice-based interfacing structures. We present a method to design pressure inlets for soft robots that act as pressure seals commonly used in high-pressure applications. Each solution is tested and shown to be usable in practical applications in soft robotics and adjacent fields.**

I. Introduction

Over recent years, soft robotic systems have been developed for a wide range of applications, being used in minimally invasive surgery [1], [2], grippers [3], [4], and miniature locomotion systems [5], [6]. Largely facilitated through increasingly affordable additive manufacturing techniques [7] such as Filament Deposition Modeling (FDM), resin-based Stereolithography (SLA), and Digital Light Processing (DLP) methods, their popularity has allowed for soft robotics to keep growing as a field of research. However, while the working principles of soft robotic manufacturing are well understood, manufacturing problems persist. Detailed solutions to specific manufacturing problems are rarely documented in articles and require researchers to develop their own methods to apply or reproduce findings of other labs [8].

When considering the open sharing of solutions to manufacturing problems, a comparison can be made to the maker community. This community solves problems by using the available equipment to minimise additional costs while aiming for maximum project success, allowing for potential upscaling of the process. Furthermore, they share these solutions with other creators within the community through forums, blogs, and even video hosting sites, increasing the collective toolkit of the community. Adopting similar transparency in presenting solutions to problems would benefit the soft robotics community while opening doors for potential upscaling in the industry. In this paper, we focus on solutions for common manufacturing problems by presenting three problems encountered in our lab.

For silicone soft robots, FDM printers are often used to create the moulds necessary to manufacture them [9]. However, rapidly creating highly detailed moulds on these 3D printers is impossible. With resin 3D printers reaching accuracies in the micron range [10] and becoming more affordable every year, switching to this type of printer is an attractive choice. However, the intrinsic silicone-inhibiting properties of photocuring resins, which cause platinum-cure silicones to stop curing and remain liquid, prevent the widespread use of resin-based parts for silicone moulds. This widely documented problem within the maker community [11], [12] has not received widespread academic attention. As observed by [13], inhibition in resin-printed moulds is reduced after repeated use and lengthy UV exposure under sunlight after printing removed inhibition altogether. As elaborated on in [14], additional UV-curing and heat treatments can make resin-printed moulds suitable for PDMS, another platinum-cure silicone. Both articles give a good insight into the origin of the inhibiting compound and avenues for removing it from the mould. However, the described methods are lengthy, requiring treatment times of over 24 hours, or risk damaging the integrity of the mould due to the high temperatures used. To this end, in Sec. II, we improve upon the findings presented in [13] and [14] to generalise the required post-processing techniques by taking inspiration from techniques used within the maker community.

Another challenge that persists with the interaction of silicone and rigid components is the inability of silicone to adhere to most materials due to their low surface energy [15]. This complicates the purposeful adherence of rigid materials to soft actuators for mounting, integration, and functionality purposes. Current solutions to keep soft robots in place come in the form of dedicated mounts or clamps that hold the actuator in place using elastic and friction forces [16], [17] or performing a surface treatment to aid in adherence such as primers or flocking [18]. In Sec. III, we focus on solving this problem through geometric design by developing and testing embedded lattice structures suitable for bonding silicone.

The difficulties of bonding rigid and silicone components also result in problems when designing high-pressure inlets. Typical pressure inlets exploit the elasticity of silicone rubbers to create an air-tight seal [16], [19]. However, as the

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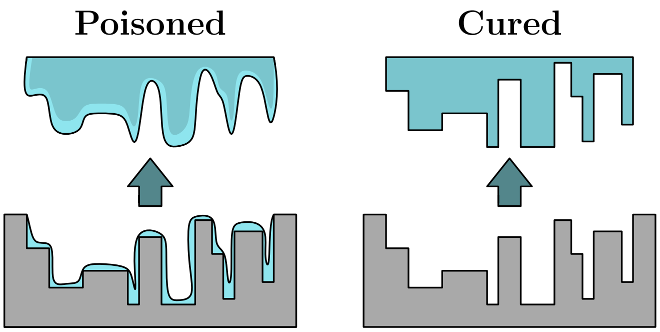


Fig. 1: The difference between inhibited and properly cured silicone. Curing is inhibited when the silicone gets poisoned where it contacts the mould, leaving the viscous liquid uncured silicone covering the part. The successfully cured silicone instead has sharp edges that follow the mould exactly.

internal pressure increases, the chance of leakage increases. In Sec. IV, we take inspiration from high-pressure piping systems by developing an embedded silicone pressure seal through mould design.

In Sec. V, we show multiple applications for the manufacturing techniques we describe in Sec. II, III, and IV. By drawing attention to the knowledge found in non-academic resources and presenting multiple solutions to common manufacturing problems, we hope to support and inspire other soft robotics researchers to develop and share their manufacturing solutions for the benefit of the wider community.

II. Problem 1: Post-processing of SLA/DLP Printed Moulds to Prevent Silicone Inhibition

Silicone inhibition is a phenomenon that can occur with platinum-cure silicone rubbers when it comes into contact with inhibiting compounds [20]. This contamination of inhibiting compounds in the silicone, also called poisoning, prevents curing, leaving the resulting silicone softer with a viscous exterior or completely uncured, where the silicone remains liquid. Photocuring resin used in SLA/DLP printers contains an inhibiting compound that prevents using these parts for silicone moulds, otherwise resulting in inhibition occurring where the silicone touches the mould as shown in Fig. 1. To take advantage of the high precision of SLA/DLP printers in silicone moulding, we require methods to seal or remove the inhibiting compound to prevent silicone inhibition.

A. Methods: Procedures to prevent inhibition

Conventional solutions to this problem involve creating a barrier between the inhibitor and silicone, which is also recommended by silicone manufacturers [11]. Recommended sealants include epoxy resins and polyurethane coatings. However, these leave thick and uneven build-up on the parts visible to the naked eye. This complicates their use for silicone moulds, as small crevices will be filled up with these sealants, and corners will be rounded due to the capillary effects of the coatings in liquid form. An alternative, commercially available solution that does not suffer from these problems is Inhibit-X, which describes itself as a single-component low-viscosity liquid that protects against curing inhibition [21]. The liquid quickly enters every crevice and, while evaporating, creates an imperceptible coating that preserves fine details sealing the part. However, as Inhibit-X is a chemical, it requires a fumehood or well-ventilated area to apply to large quantities of moulds, making it impractical for labs that don't already have the necessary equipment. Furthermore, when using Inhibit-X, the chemical will need to be reapplied after each use and forgetting to use a release spray causes the silicone to fuse to the mould [21].

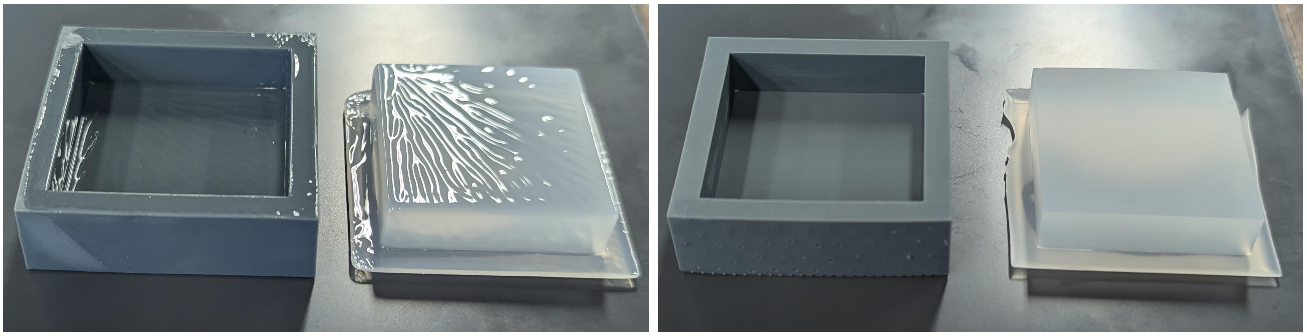
With the drawbacks of the sealing solutions for moulds, removing the inhibitor, likely originating from insufficiently cured resin contained in printed parts [13], [14], from the mould is the next step. As indicated by [13], additional UV-curing proves helpful in preventing inhibition, while a subsequent heat treatment further improves curing behaviour [14]. However, the treatments in [13], [14] either have treatment times of over 24 hours or the treatment temperatures are too high, risking the integrity of the mould and risk warping the geometry. Furthermore, [13] only makes observations, as the research focuses on not solving silicone inhibition but taking advantage of it. Additionally, the method in [14] is only tested with PDMS, which, while also a platinum-cure silicone, differs from the silicones commonly used in soft actuators.

Due to the drawbacks of the methods described in academic literature, we instead turn to the maker community, where this inhibition problem is widely documented due to the popularity of silicone rubbers and SLA/DLP printers. To prevent inhibition, creators in the maker community tend to use coatings, as silicone is often used to create a mould, which can subsequently be used to make copies of the originally resin-printed model. However, creators using moulds to manufacture functional components focus more on permanent solutions that retain the fidelity of the mould by removing the inhibitor from the part. One of the most prominent blog posts about this subject is found at [12], which describes curing the parts underwater and soaking them in water for prolonged periods before performing a second cure. Similarly, [22] discusses the effectiveness of 48-hour isopropyl alcohol baths to remove the remaining inhibitor.

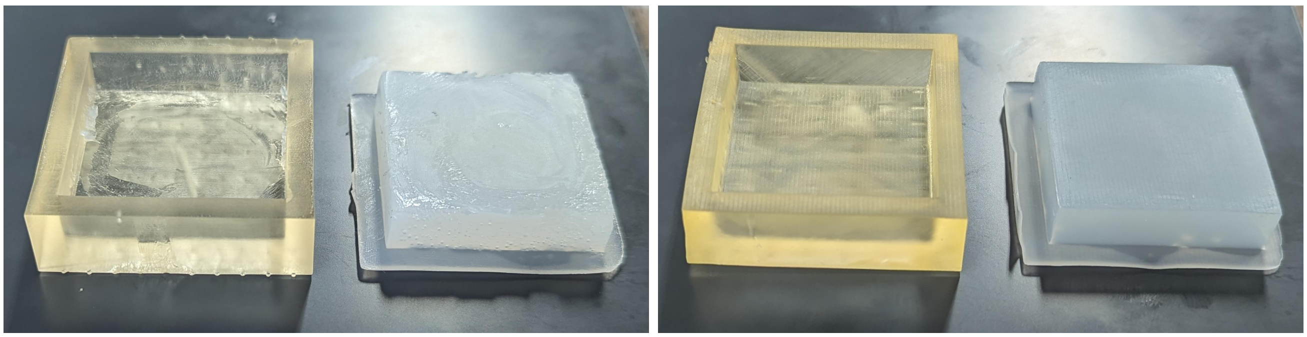
One method in line with the findings in academic literature [13], [14] that holds a lot of promise is [23]. Here, they perform a post-curing time of 4 hours, followed by a 4-hour heat treatment at $180\,^{\circ}\mathrm{F}$ / $82\,^{\circ}\mathrm{C}$, with the resulting part showing no signs of curing inhibition. This method is not flawless, as [23] states; this method still leaves minor air bubbles where the silicone touches the printed part. However, as this technique is relatively hands-off, inexpensive, avoids the high-temperature ranges used in [14], does not add any coating or use chemicals, and can be performed within a day, it is worth testing, which is done in Sec. II-B

B. Results

To test the method proposed in [23], we make one change to generalise it for different photocuring resins. We include the standard post-curing procedure for the used resin as an



(a) Resin-printed moulds made from Elegoo Space Grey 8K resin using the standard post-curing procedure (left) and the presented post-curing procedure (right). On the left, the uncured silicone is recognised by the glossy finish, with a wavy pattern due to the viscous uncured silicone being pulled out of the mould. On the right, the silicone is cured completely, recognised by the matte finish and sharp edges matching those of the mould.



(b) Resin-printed moulds made from Wanhao water-washable clear resin using the standard post-curing procedure (left) and the presented post-curing procedure (right). On the left, the edges of the silicone were insufficiently cured, as seen by the glossy finish; these parts are sticky to the touch and softer than properly cured silicone, causing tears during demoulding. On the right, the silicone is cured properly, recognised by the matte finish and the sharp edges matching the mould.

Fig. 2: Comparison between resin printed moulds with and without the presented post-curing procedure. Uncured silicone is recognised by a glossy finish and a viscous liquid covering the sample where it touched the mould. Insufficiently cured silicone is recognised by the non-uniform finish where it was in contact with the mould, resulting in patches of silicone sticky to the touch and softer than desired, causing tears during demoulding. Properly cured silicone is recognisable by the uniform matte finish on the entire part, with sharp edges indicating a perfect cast of the mould.

initial step, resulting in the following generalised step-by-step procedure:

- **Standard UV-cure** of the printed part following the resin's recommended guidelines.
- **Extended UV-cure** of the printed part for 4 hours at room temperature.
- **Heat Treatment** of the printed part for 4 hours at $82\,°\mathrm{C}$.

We apply these methods to a generic square mould with sharp edges made with two resins known to have inhibition problems: Elegoo Space Grey 8K and Wanhao water-washable clear resin, which both have a recommended post-curing time of 10 minutes at room temperature. We fabricate two copies of our benchmark for each resin, using the standard and altered post-processing techniques to assess whether the moulds can be used for platinum-cure silicone.

As observed in Fig. 2, the moulds post-cured using the standard procedure show signs of inhibition. The Elegoo Space Grey resin shows an extreme case of silicone inhibition, leaving a glossy, viscous layer at the boundary where the silicone and mould touched. As the silicone was demoulded, this viscous layer was deformed, resulting in a wavy pattern seen in the figure. Meanwhile, the Wanhao clear resin shows less clear signs of inhibition. Still, during demoulding, parts of the edges were significantly softer than properly cured silicone, causing tears and leaving parts stuck in the mould. Furthermore, the edges are rounded, and some parts are glossy and sticky to the touch, similar to the observed characteristics of uncured silicone. While the reason for this decreased inhibition is unknown, we hypothesise that the mould's transparency allows the UV light to penetrate deeper, curing it more efficiently. Regardless, even with this more efficient curing, the silicone in the untreated Wanhao clear resin cured insufficiently, making it unusable for soft actuator fabrication.

After applying the generalised post-processing method to the second set of moulds and filling them, the silicone could cure completely. There are no signs of uncured or partially cured silicone, with the stiffness being uniform around the part. Additionally, contrary to what was reported in [23], no air bubbles can be identified at the edges of the silicone, resulting in a perfect reproduction of the inside of the mould. With sharp edges, uniform material properties, no moulding defects, and a mould that can be reused without needing to remove uncured silicone, we conclude that the presented post-processing method prevents silicone inhibition in SLA/DLP printed moulds.

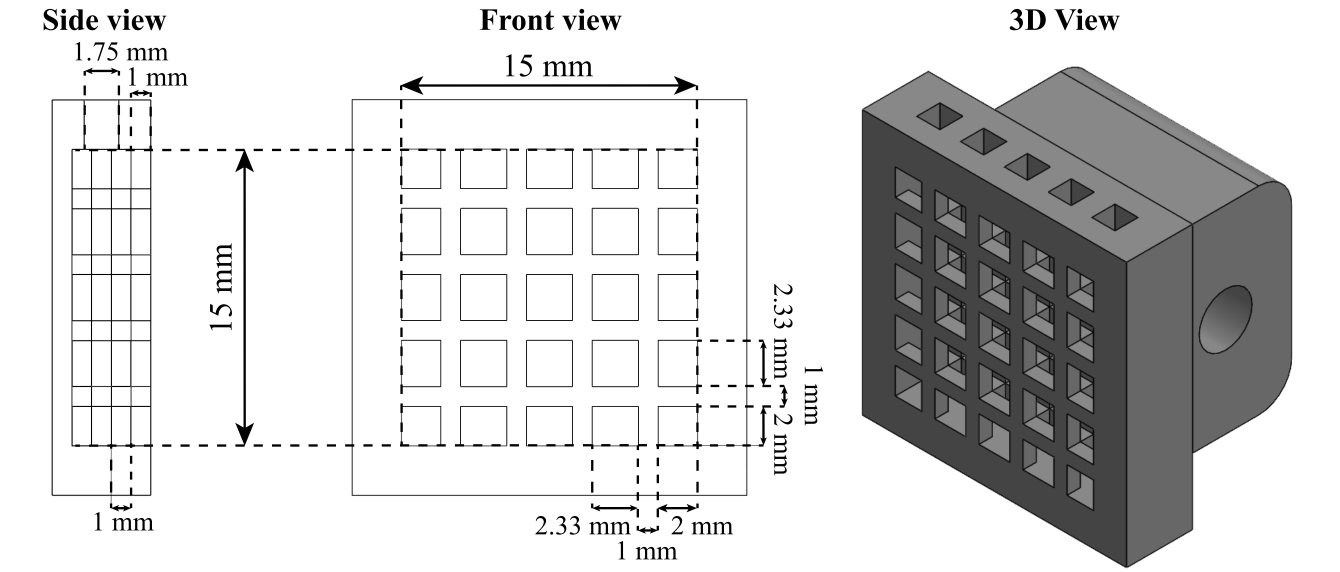


Fig. 3: Design of the lattice structure used to interface with the silicone. The dimensions were chosen to account for manufacturability, strength, and silicone flow, with the cross-sectional area chosen to be in the range of standard PneuNet-style actuators.

III. Problem 2: Material Interface for Silicone Moulding

Adhering silicone to other components is an ongoing challenge within the soft robotics community, as silicone is non-adhesive to most materials. Conventionally, by taking advantage of the elasticity of the silicone, simple clamps can be used to affix silicone to rigid components [16], [17]. With this method, actuators can be removed or replaced as desired, but the size constraints of the clamps limit the designs, and the strength of the connection is limited by the friction forces generated by the clamp. Alternatively, spray-on primers or adhering fibres to a part with flocking [18] allows silicone to be bonded to rigid parts permanently. However, these methods require chemicals, which is impractical for labs without the necessary facilities. Taking inspiration from fabric-silicone composites [24], we design a 3D-printable interface geometry that can be embedded into components to allow for strong bonding between rigid and silicone components.

A. Methods: Design of the Interface

We design the 3D-printable interface to allow liquid silicone to penetrate the physical structure, similar to the fabrication of fabric composites. This results in a layered lattice structure that the silicone can easily flow through while filling up a mould, as shown schematically in Fig. 4. When designing the lattice structure, we focus on three qualities: strength of the lattices, strength of the silicone when filled, and manufacturability. As a design constraint, the 3D-printable components should be printable on standard commercial FDM printers without supports.

For this lattice structure, the total cross-sectional area where we place the interface is $15{\times}15\,\mathrm{mm}^2$. The precise dimensions are chosen arbitrarily; however, care is given to ensure they remain in the range of the cross-sectional area of PneuNet-style soft actuators [25]. The individual lattices have a cross-sectional area of $1{\times}1\,\mathrm{mm}^2$ to ensure printability by FDM printers, as most FDM printers use a nozzle diameter of $0.4\,\mathrm{mm}$. Using $1\,\mathrm{mm}^2$ also provides good durability for the lattices to help them withstand forces. The interface should be designed to provide enough space for the silicone to fill such that there is an approximately even ratio of silicone/rigid when filled. To enhance the connection strength of the lattice structure, we mitigate excess bending of the lattices by connecting the layers to each other. The dimensions we used for our lattice structure and the 3D model equivalent are shown in Fig. 3. This structure has been tested to be printable with FDM and SLA printers without support material. Additionally, any imperfections due to the lack of supports provide additional space for the liquid silicone to penetrate, potentially increasing the strength.

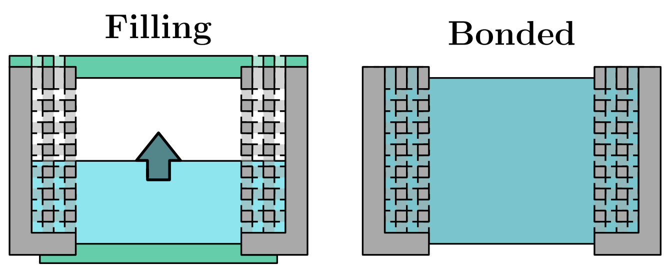


Fig. 4: Schematic side view of the filling of a mould with interfacing components. When filling the mould from the bottom, air will be pushed out through the vent holes, resulting in an end product with evenly distributed and bubble-free silicone rubber.

We add a row of air vents above the lattice structure to further enhance silicone flow. This will allow air to be pushed out when filling the mould and prevent air bubbles inside the lattice structure that could compromise strength. By filling the mould from the bottom, we can achieve an even and bubble-free silicone rubber, schematically shown in Fig. 4.

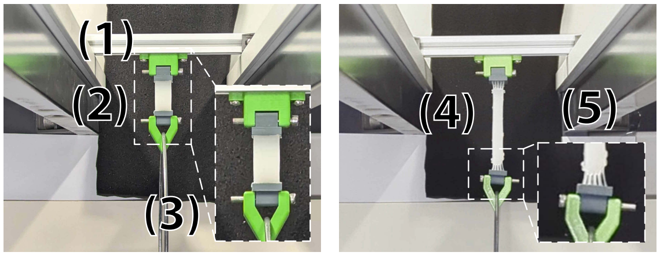


Fig. 5: Experimental setup to measure the connection strength of each silicone rubber. (1) the affixing point of our samples, which remains stationary during an experiment. (2) a sample of two interfacing components bonded with silicone rubber according to Fig. 4. (3) an expanded view of the sample. (4) a stretched sample after applying a load. (5) an expanded view of the interfacing component under load; note the silicone strands between the silicone body and interfacing component, these are the point of failure when the loading capacity is reached.

B. Results

To assess the strength of the interface, we 3D-print the rigid parts according to the specifications and design shown in Sec. III-A. We use an SLA printer to manufacture the interfacing components and post-process them using the method described in Sec. II. The mould is reminiscent of the mould shown in Fig. 4, where we can slot in two interfacing components with a $15{\times}15{\times}30\,\mathrm{mm}^3$ volume between them.

To ensure the method works for different silicones, we create four samples with different commonly used silicones for soft robotics:

- Ecoflex 00-30,
- DragonSkin 10,
- DragonSkin 20,
- Smooth-Sil 945.

To test the samples, we designed an experimental setup to vertically affix our samples so that the other end can be loaded by attaching weights. We gradually increased the load applied to our sample. As the load increases, the sample will stretch and snap, at which point we can measure the total strength of the interface. The used experimental setup is shown in Fig. 5, with an example of a sample at rest and when it is about to break.

After performing our experiments, we can see that depending on the type of silicone used, the maximum load that can be carried depends on the silicone's stiffness. From our experiment, Ecoflex 00-30 could handle $\sim 21.5\,\mathrm{N}$, DragonSkin 10 $\sim 73.5\,\mathrm{N}$, DragonSkin 20 $\sim 84.3\,\mathrm{N}$, and Smooth-Sil 945 $\sim 110.5\,\mathrm{N}$. Furthermore, the breakpoint in each sample was at the boundary of the silicone body and rigid connecting piece, as the silicone strands penetrating the lattice structure failed the quickest. Further optimisation is possible by changing the ratio of rigid and silicone in a given cross-section of the interface. However, as the optimal design depends on the chosen materials, application requirements, and size constraints, it was decided to leave this topic as a potential topic for future study. The measured strength of the interface is satisfactory for soft robotics, as current soft robots are mostly tested with tensile forces of up to $2\,\mathrm{N}$ [26], [27], [28]. It is important to note that the interfacing method works irrespective of the type of silicone used. Still, for silicones that are thicker in their liquid state, injection moulding or larger holes between the lattices are recommended to ensure proper penetration into the interfacing structure.

IV. Problem 3: Integrated Soft Robotic Pressure Seal

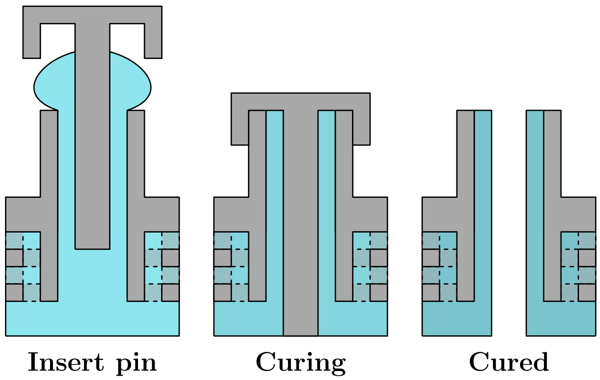
Another common but often poorly solved problem with soft robotic systems is how pressure inlets are attached to the system. Commonly used throughout academic soft robotics research, pressure inlets are connected by inserting a hose with some glue directly into the soft actuator, letting the stretched silicone or external adjustable component apply the necessary compressive force on the hose with glue to create an airtight seal [19], [29]. While functional, this type of inlet will start leaking at higher pressures, with little control over the maximum achievable pressure. Taking advantage of the rigid-silicone interfacing method described in Sec. III, we tackle this problem by taking inspiration from high-pressure systems and developing a pressure seal that can be incorporated into soft-robotic systems.

A. Methods: Working Principle and Manufacturing

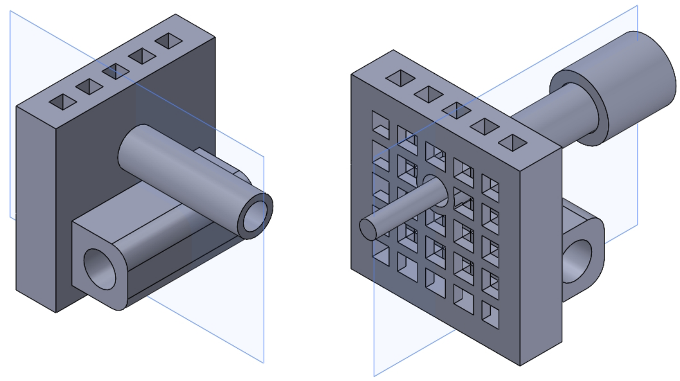
In high-pressure applications, a pressure seal is a sealing method that exploits the internal pressure to apply a force to an area where two, typically rigid, components touch to prevent leakage. An essential property of the pressure seal is that its sealing capability is proportional to the internal pressure, in which the sealing properties improve with increasing pressure. This contrasts with other commonly used seals used for piping, where the pressure it can withstand depends on the pre-load applied to the seal and the material used. Pressure seals rely on soft materials to be compressed into points prone to leakage through internal pressure. Typically, a pressure seal would be placed where two rigid components touch; however, this approach must be rethought because part of the system is already soft.

As a basis, we will integrate the pressure seal into the interfacing components described in Sec. III. When constructing this inlet, there is a point where the rigid inlet transitions to the silicone. However, as silicone does not adhere to the rigid surface, this transition is the primary point where leakages occur when only using this approach. This problem is avoided by extending the silicone through the inlet, creating a silicone sleeve covering the inside walls. When the system is pressurised, the thin sleeve will be pressed into the inner wall of the inlet, sealing it the same way a pressure seal would.

To create such a sleeve, we design our connecting pieces with inlets and place them in the mould as usual. When injecting silicone, the silicone will eventually eject from the inlet, at which point we put a capped pin into the inlet. We apply spray-on mould release on the capped pin to ensure it can be removed from the mould easily after curing. After curing, when we remove the pin, a thin silicone sleeve is left on the inside of the inlet, which is continuous with the main silicone body. This manufacturing technique for this silicone sleeve is shown in Fig. 6 (a).



(a) Schematic cross-section of the integrated silicone pressure seal manufacturing process. We insert a pin after injecting silicone, which remains in place during curing. After curing, we remove the pin, leaving a thin silicone sleeve inside the inlet.



(b) Diagonal view of the front and back of the 3D modelled part showing how the manufacturing principle is applied. The pin extends through the inlet and ends at the point where the internal geometry of the soft actuator starts. Covering the pin with a spray-on release agent before inserting helps remove the pin after curing. The blue plane marks the cross-section schematically shown in (a).

Fig. 6: Schematic and modelled examples on manufacturing the desired silicone sleeve for the pressure seal. (a) shows the manufacturing procedure, where we insert a pin after inserting silicone to avoid air bubbles and promote easy silicone dispersion through the inlet. (b) shows a modelled example of manufacturing the pressure seal inlet, combining the principles described in (a) with the interfacing structures presented in Sec. III.

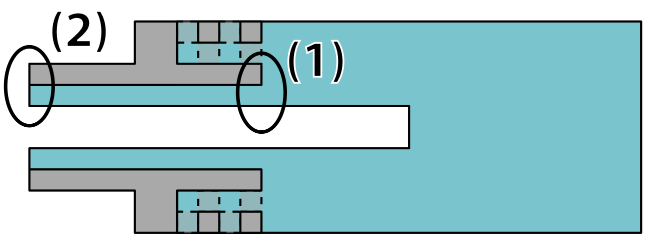


Fig. 7: Schematic representation of the internal structure of the tested samples, with the weak points circled. (1) is a weak point that can rupture at high pressures but is unlikely to occur before the rest of the soft actuator breaks. (2) is a weak point due to the silicone not sticking to the rigid walls, but it will not cause a leak if the pressure seal functions as designed.

B. Results

To assess the strength of the pressure seal, we manufacture several samples that use the solution presented in Sec. III to bond the silicone to a rigid part and the method shown in Fig. 6 (a) to create the pressure seal, where the resulting rigid interface and inlet structures for the mould are shown in Fig. 6 (b). The pressure channel is designed to extend into a solid silicone brick, resulting in two potential points of failure, both marked in Fig. 7. Weak point (1) is where the sleeve is at the boundary of the main silicone body and the interfacing part, which could fail if the pressure is too high and the silicone sleeve breaks. This point of failure is unlikely in an actual soft actuator, as the rest of the actuator will undergo more expansion and is thus more likely to fail. Weak point (2) is where the sleeve ends; as the silicone does not bond to the rigid surface, air can be blown between them. However, as the pressure increases, this gap will close, sealing itself just as the sleeve is designed to do. The samples are made from Ecoflex 00-30, DragonSkin 10, DragonSkin 20, and Smooth-sil 945, and we assess two inlets per material.

When testing the strength of the seals, we applied an overpressure of $140\,\mathrm{KPa}$, which was deemed as high enough as most soft actuators rarely surpass $100\,\mathrm{KPa}$. The DragonSkin 10, DragonSkin 20, and Smooth-sil 945 inlets could withstand $140\,\mathrm{KPa}$ without complications. When the pressure in the Ecoflex 00-30 inlets was increased, the main body of silicone would expand significantly, indicating that the sample was ballooning due to the low material stiffness. However, as the pressure seal was still able to hold with extensive deformation, the Ecoflex 00-30 sample is deemed a successful trial, as the pressure inlet is no longer a weak point in the design. With each of the samples having a successfully sealed inlet, we conclude that this method of inlet design will allow for compact, strong inlets for soft systems combined with rigid components.

V. Applications

To demonstrate the effectiveness and versatility of the approaches described in Sec. II, III, and IV, we briefly showcase several applications for these manufacturing methods.

A. Integration into Soft Actuators

The PneuNet-style soft actuator [30] is a common type of soft actuator used in the field. Commonly augmented with inextensible layers to enhance the bending properties, using other materials for different actuator parts is an interesting way to enhance its capabilities. One approach is to incorporate rigid components at the ends of the actuator as shown in Fig. 8, which was done using the method described in Sec. III. The obtained benefits depend on the purpose of the included rigid components. One benefit is the possibility of including an inlet like the one described in Sec. IV. The intended benefit of these rigid components in the PneuNet style actuator is to attach external flexible sensors into the soft actuator without embedding them.

B. Haptic Inflatable Dome

Within haptic applications, pneumatic systems help with stimulating the senses without discomfort. Usually, these pneumatic systems are small, capable of being made entirely from soft materials to attach to one's hand [31]. In a project on rehabilitation, an inflatable hand-sized soft silicone dome

Fig. 8: PneuNet-style soft finger with integrated rigid components.

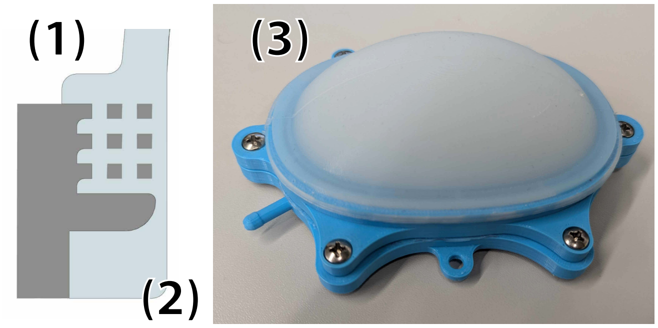
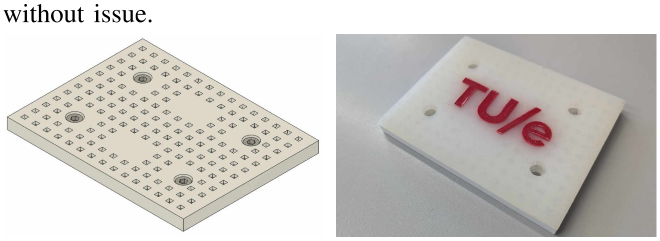


Fig. 9: Schematic of the silicone interfacing area and a manufactured dome. (1) is the interfacing area where silicone bonds to the outer ring. (2) is excess silicone that can be compressed during assembly to create an air-tight seal. (3) is a manufactured example of a fully assembled dome.

was used as an actuator for haptic feedback. As shown in Fig. 9, using the material interface of Sec. III, a silicone dome can be embedded onto a ring that, when compressed during assembly, fully seals the system. This allows for embedding various sensing methods on the base plate to create a functioning haptic feedback system.

C. End-effector padding

Efficiency, cycle time, and cost are essential when upscaling depalletising processes. While robotic manipulators can already perform repetitive motions quickly and efficiently, designing an end-effector that can handle a variety of objects remains a challenge. To tackle this, a silicone friction pad was designed to avoid slipping when manipulating objects that can be attached to a modular passive end-effector. As shown in Fig. 10, a 3D-printed plate with a lattice structure allows the liquid silicone to penetrate the structure to create the desired friction pad. After curing, the silicone pad, now bonded to the rigid plate, can be screwed into the end-effector without issue.



(a) Schematic view of the lattice structure to create a silicone friction pad. **(b)** Manufactured silicone friction pad that can be attached to an end-effector

Fig. 10: Schematic and manufactured end-effector components. With the lattice structure shown in (a), liquid silicone can penetrate the structure to create a strong connection after curing, resulting in the silicone pad shown in (b).

VI. Discussion

When researching solutions for manufacturing problems, researchers often focus on academic literature only to find the necessary information. However, when working in fields that overlap with non-academic communities, science can benefit from using open-source information to strengthen research. With their home on blogs, forums, and even video hosting sites, the maker community contributes to their collective knowledge by asking questions, presenting solutions, and ensuring that information is freely available for whoever needs it.

We experienced this difference in available information when in Sec. II, where we attempted to use academic resources to solve the problem of silicone inhibition in resin-printed moulds. As the methods were either time-intensive, risked the integrity of the mould, or only documented the inhibition phenomenon without a definitive solution, we focused on non-academic resources. We found solutions posted on blogs that gave further insight into the causes and how to solve the problem, and eventually, a YouTube video [23] showed a method with a lot of promise. After testing the generalised method based on this video and finding that it works even better than reported initially, it shows the benefits of actively reaching outside academia for inspiration and learning from doing.

While offering a good starting point for researchers, the practical skills of the maker community are often not immediately suitable for citation. By testing the promising methods presented in these sources, verifying the results and reporting on them while citing the non-academic source, this information can be presented to a more focused audience to help researchers solve manufacturing problems. Inspiring this paper, we believe that adopting a policy of open sharing of manufacturing techniques, similar to the approach of the maker community, is a path to a more interconnected community. As proof of this, we have shown in Sec. V that the manufacturing techniques presented in this paper can be used for various applications. Even when a developed solution is only an alternative to an existing solution, the differing characteristics aid in expanding a researcher's toolkit when designing soft systems. Openly sharing these methods, regardless of significance, will benefit the wider soft robotics community, helping researchers create new and innovative soft robots.

VII. Conclusions

In this paper, we present three solutions to manufacturing problems faced within the soft robotics community. The efficacy of these solutions was tested to assess whether the original problems were solved. We show that using our post-processing techniques, we can use resin-printed moulds for platinum-cure silicones without encountering inhibition. Furthermore, our silicone bonding strategy can handle forces larger than soft robots are expected to handle. Finally, our pressure seal can handle pressures higher than soft robots are typically designed for without having encountered the pressure limit of the presented solution. We also present multiple applications for the manufacturing techniques, showing the range of applications and further proof of their success.

In future work, these manufacturing techniques open exciting avenues for combining soft robots with rigid components. To conclude, by sharing our manufacturing techniques, we aim to inspire other labs to continue sharing their methods to create a more interconnected soft robotics community.

Acknowledgments

We thank Kevin Kieboom for integrating rigid components into a PneuNet-style soft actuator, Daan Kriellaars for developing the inflatable dome for haptic feedback, and Lou Hacking for designing the modular silicone friction pad. This has allowed us to see the methods' potential in applications both in and outside the soft robotics field.

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