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Investigation of the performance of the elastomer-based soft robotic gripper produced by the bubble casting technique

Kabarcık döküm tekniği ile üretilen elastomer esaslı yumuşak robotik tutucunun performansının incelenmesi

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Abstract

A soft robotic actuator was produced by the bubble casting technique, which is composed of elastomeric material. Investigations were conducted to determine how the viscosity of the liquid elastomer affected how the robotic actuator bent. The gripper's curvature, response time, and load-carying capacity were measured, and the relation between applied air pressure and these characteristics was examined. Moreover, the effect of environmental factors (dry, wet and oily) on the load-carrying capacity of the gripper was investigated. These findings demonstrate that as applied air pressure is increased, the gripper's response time, curvature, and load-carrying capacity all increase. For all applied pressures, the highest load-carrying capacity of the gripper was observed in a dry environment. The grippers load-carrying capacity in a dry environment was approximately 2.5 g, 3.5 g, and 5.9 g at pressures of 30 kPa, 35 kPa, and 40 kPa, respectively. By altering the waiting time, the elastomer's viscosity could be managed. The ideal waiting time was found to be between 3 and 4 minutes for optimal bending performance. If the soft robotic gripper is improved to achieve greater performance, it will be suitable for real-world applications.

Keywords: Bubble casting technique, Elastomer, Performance, Soft robotic gripper, Soft robotic actuator

Öz

Kabarcık döküm tekniği ile elastomerik malzemeden oluşan yumuşak bir robotik aktüatör üretilmiştir. Sıvı elastomerin viskozitesinin robotik aktüatörün bükülme şeklini nasıl etkilediğini belirlemek için araştırmalar yapıldı. Tutucunun eğriliği, tepki süresi ve yük taşıma kapasitesi ölçülmüş ve uygulanan hava basıncı ile bu özellikler arasındaki ilişki incelenmiştir. Ayrıca çevresel faktörlerin (kuru, ıslak ve yağlı) tutucunun yük taşıma kapasitesi üzerindeki etkisi incelenmiştir. Bu bulgular, uygulanan hava basıncı arttıkça tutucunun tepki süresinin, eğriliğinin ve yük taşıma kapasitesinin tamamının arttığını göstermektedir. Uygulanan tüm basınçlar için tutucunun en yüksek yük taşıma kapasitesi kuru ortamda gözlenmiştir. Üretilen robotik tutucuların kuru ortamda yük taşıma kapasitesi, 30 kPa, 35 kPa ve 40 kPa basınçları için sırasıyla yaklaşık 2,5 g, 3,5 g ve 5,9 g olmuştur. Bekleme süresinin değiştirilmesiyle elastomerin viskozitesi yönetilebilir. Optimum bükme performansı için ideal bekleme süresi 3 ile 4 dakika arasında bulunmuştur. Yumuşak robotik tutucu, daha yüksek performans elde etmek için geliştirilirse, gerçek dünya uygulamaları için uygun olacaktır.

Anahtar kelimeler: *Elastomer, Kabarcık döküm tekniği, , Performans, Yumuşak robotik tutucu, Yumuşak robotik aktüatör*

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1. Introduction

Soft robotic actuators can easily be used as soft robotic gripper to achieve complex tasks such as gentle gripping (Hawkes et al., 2017; Overvelde et al., 2015; Polygerinos et al., 2015; Roche et al., 2014; Yang et al., 2016). Using soft robotics and gripper technology, real-world examples of object detection and handling jobs include picking and arranging items in a warehouse, handling delicate or irregularly shaped products in manufacturing, and even supporting surgical procedures in the medical industry (Majidi, 2014). Because of their special blend of flexibility and bioinspired motion, soft robotic actuators are more appealing for a range of cutting-edge applications than rigid robots are (Majidi, 2014). Recent advancements in modelling, computation, and manufacturing that make it possible to design, program, and assemble different kinds of soft robotic grippers are the driving forces behind this emerging field. While soft actuators that are activated chemically, thermally, electrically, or magnetically have been demonstrated (Acome et al., 2018; Boley et al., 2019; Guseinov et al., 2020; Hu et al., 2018; Kanik et al., 2019; Kim et al., 2018; Sydney Gladman et al., 2016), silicone-bodied pneumatic robots that are powered by pressurized voids have attracted considerable attention due to their straightforward and fast actuation (Gorissen et al., 2017; Polygerinos et al., 2017). Soft pneumatic actuators are among the most traditional but are still widely used actuation methods in soft robotics today because of their many benefits, such as their affordability, robustness, and ease of manufacture. The process of actuator creation involves applying pressure from a gas or liquid to a highly malleable chamber (Gorissen et al., 2017; Polygerinos et al., 2017).

On the other hand, it is difficult to manufacture soft pneumatic actuators, especially the void, so sequential moulding techniques and removable frameworks that are customized for particular actuators are typically used. For example, bubble casting is a simple and adaptable fabrication technique to produce monolithic actuators using the principles and instruments of fluid mechanics developed by Jones et al. in 2021. However, the performance of the soft robotic actuator produced by the bubble casting method as a gripper has not been investigated in detail (Jones et al., 2021).

In this paper, a pneumatic elastomer-based gripper was fabricated by bubble casting technique for use in soft robotic grippers. Firstly, the effect of the viscosity of the liquid elastomer on the bending behaviour of the robotic gripper was examined. Secondly, the relation between applied air pressure and the gripper's curvature, response time, and load-carrying capacity. Understanding how environmental factors (dry, wet, and oily) affect the gripper's ability to support loads was investigated. This work not only describes the impact of air pressure and the working environment on the performance of the gripper but also reports an ideal waiting time for the optimum bending behaviour.

2. Material and method

Schematic illustrations for the fabrication steps of the bubble-casting soft robotic grippers are represented in Figure 1. Firstly, the mould with a cylindrical hole of 4 mm diameter between two acrylic plates was prepared by CNC milling (step i). Vinyl polysiloxane (VPS) silicone elastomers were used to make the soft robotic grippers. Chemical, physical and mechanical properties of the vinyl polysiloxane are given in Table 1. The prepolymer base (Zhermack elite double 22) and curing catalyst (Zhermack elite double 22) were mixed manually in a 1:1 weight ratio to start the curing process. The polymer melt progressively solidifies at $t = 0$ after mixing, changing the elastic body from the viscous fluid. Then, the mould was filled by injecting the uncured elastomer liquid (step ii). After, the air was injected into the elastomer while it was still liquid to create an elongated bubble that formed the gripper's inner void (step iii). The liquid elastomer was then allowed to cure for 10 minutes at room temperature (step iv). Afterwards, the cured VPS elastomer was demoulded (step v). Finally, by attaching a ~ 2 mm thickness strain-limiting layer (Dragon Skin 10) to the cured elastomer, the bubble-casting soft robotic was acquired (step vi).

Table 1. Chemical, physical and mechanical properties of the vinyl polysiloxane

Chemical formula	Hardness (Shore A)	Load at break	Elongation at break	Tear resistance
$[(CH2=CH)CH3Si-O]$	23	2.6 N/mm^2	440 %	5.3 N/mm^2

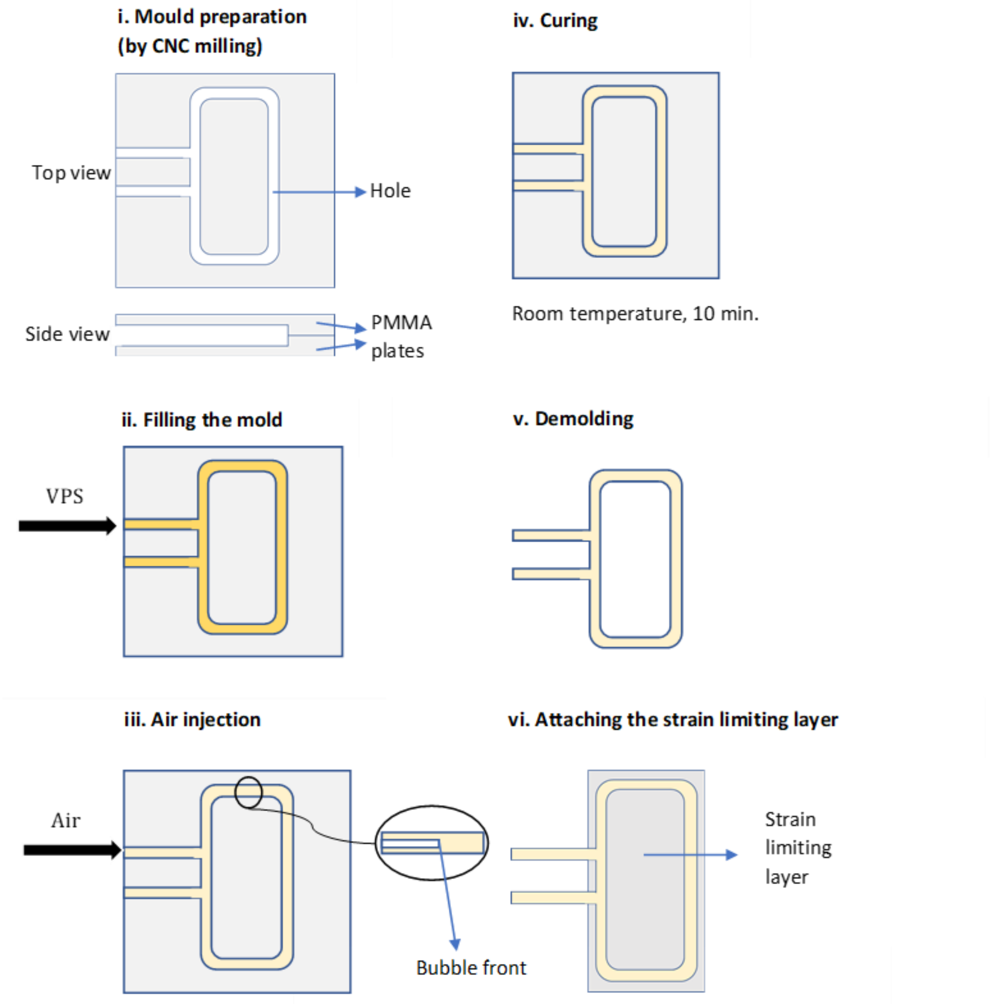

Figure 1. Schematic drawings of the fabrication processes of the bubble-casting soft robotic gripper.

A digital microscope (Jiusion Wifi USB Digital Handheld Microscope) was used to examine the specimen's cross-section images. To take the photographs of the grippers, a cell phone camera was used. Used a syringe fitted on a 6V micro air pump to inflate the soft robotic grippers after piercing them with syringe needles. A manometer is used to measure air pressure, a range of 0-100 kPa. The response time was calculated by recording all the time between the original and resultant curvature of the gripper when applied a certain pressure. The load-carrying capacity was evaluated by grasping and holding the cylindrical specimens with a known weight and a 5 mm diameter by the gripper.

3. Results and discussion

The geometric shape of the cross-section of the grippers is formed by a two-stage mechanism. The final shape is created by simultaneously gravity-driven drainage and elastomer curing after the air bubble injection causes the uncured melt to deposit a thin polymer annulus in the mould. In addition, the viscosity of the uncured elastomer right before the bubble injection has a crucial role in the cross-section shape of the gripper. Hence, the final void shape of the gripper can be adjusted by controlling the waiting time [16].

In experiments, the waiting time was changed from 0 to 5 minutes to optimize the gripper's cross-sectional geometry (Figure 2). For this purpose, we examined the bending behaviour of all samples after applying air pressure to determine the optimized cross-section geometry. Waiting time of fewer than 3 minutes, the samples did not show bending as they were torn at their joints (red dashed lines) immediately after applying pressure due to their insufficient annulus thickness (Figure 2(a-b)). The thicknesses of the thinnest parts of the annulus of the samples are 92 µm, 163 µm and 1134 µm, respectively. Additionally, the density and shore A hardness of the samples are 1.14 g/cm3 and 22, respectively. Samples with a waiting time of 3 to 4 minutes exhibited bending up to 72 % curvature without tearing (Figure 2(c-d)). For a waiting time of more than 4 minutes, the samples did not show bending due to their symmetrical void geometry (Figure 2(e-f)). The waiting time for samples with optimum geometry was determined as 3 to 4 minutes. Also, the surface of the robotic gripper did not exhibit any porosity (Figure 2(g).

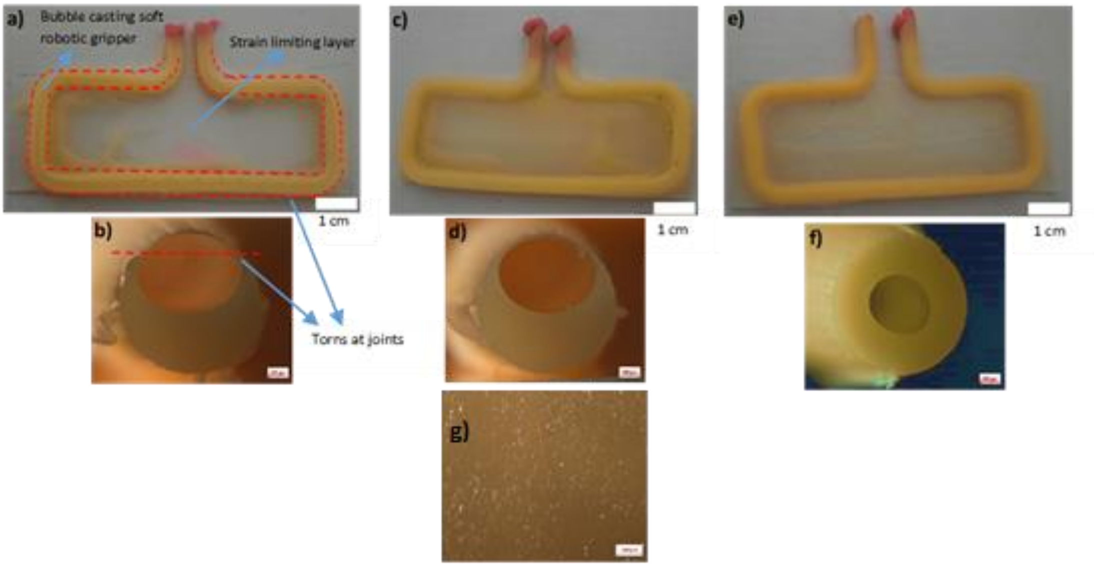

Figure 2. Representative photographs and cross-sectional digital microscope images of bubble-casting soft robotic grippers produced with various waiting times: a-b) Waiting time < 3 min. , c-d) 3 min. < Waiting time < 4 min. , e-f) 4 min. < Waiting time. g) Surface image of the gripper.

As is well known, air pressure can be used to precisely and swiftly regulate the curvature of the soft robotic gripper, which is crucial for practical applications. The curvature of the gripper is displayed in Fig. 3 as a function of air pressure. The curvature of the gripper can be precisely adjusted by controlling the air pressure, which is increased as pressure is increased up to 40 kPa. The adjustable curvature range of the gripper is 28 1/m to 72 1/m. At pressures above 40 kPa, the gripper loses its ability to bend due to tearings in the joints of the gripper. Similarly, in the literature, it was determined that the pneumatic gripper bends at pressures between 20 kPa and 40 kPa and that the bending increases as the pressure increases (Jones et al., 2021)**.**

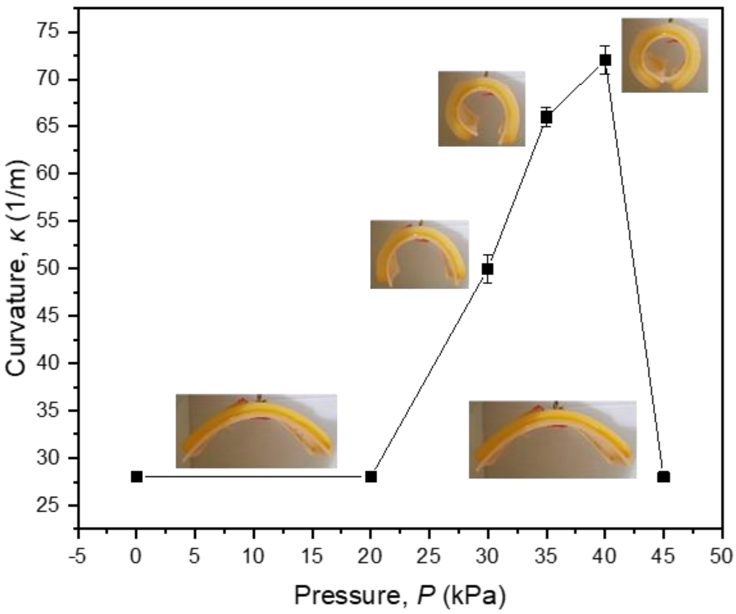

Figure 3. The soft robotic gripper curvature is a function of air pressure applied.

Figure 4 provides information about the gripper's response time. The pressure-induced change in curvature is nearly linear concerning a function of the pressure applied. As well, the robotic gripper showed a quicker response time when 40 kPa pressure was applied compared to 30 kPa and 35 kPa pressures. The pressure response rate of the gripper under 40 kPa, 35 kPa, and 30 kPa pressure were approximately 1.2 s, 2.3 s, and 5.8 s for curvature from 28 1⁄m to 50 1⁄m. The outcome is attributed to the increase in the velocity of the air entering the gripper per unit of time with the increase in pressure, as the velocity of the air increases, the inside of the gripper reaches the desired pressure more quickly, causing the gripper to bend. These results suggest that the grip and release of bubble-casting soft robotic grippers can be precisely controlled by adjusting applied air pressure. However, studies in the literature have determined that the response times of pneumatic grippers are shorter (0.05 s to 1.0 s) (Gorissen et al., 2017). Due to the thin structure of the produced robotic gripper, the soft robotic gripper lost its function as a result of tears in the elastomer when high pressures (> 40 kPa) were reached. Therefore, the response time remained short because the air pressure could not be increased.

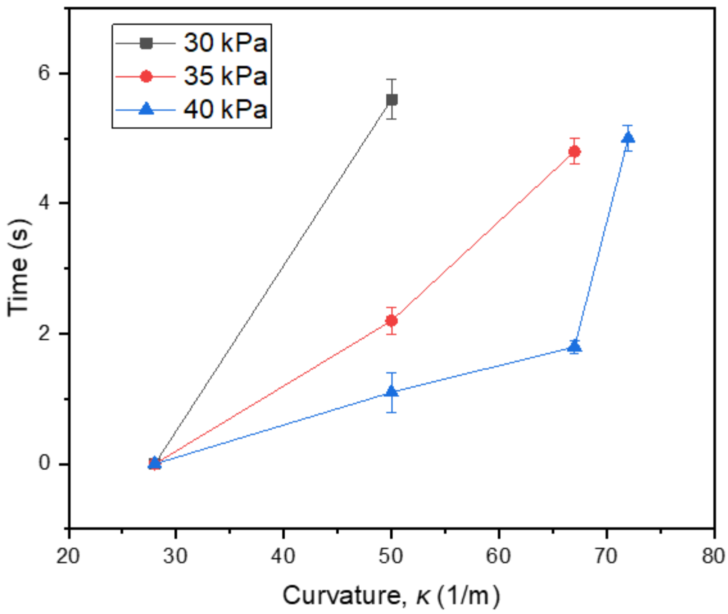

Figure 4. Response time as a function of the soft robotic gripper curvature for varied pressure.

The load-carrying capacity has a crucial role in the practical application of soft robotic grippers, as is well known. Here, the pressure-induced load-carrying capacity of the gripper was also evaluated at 30 kPa, 35 kPa and 40 kPa pressures and compared under different environments (dry, moist and oily). The load-carrying capacity of the gripper increased increasing in applied air pressure for all environments. In addition, the highest load-carrying capacity for the gripper at all pressures was observed under a dry environment because of interactions of van der Waals between the surfaces of the gripper and the sample. Under a dry environment, the load-carrying capacity of the gripper for pressures of 30 kPa, 35 kPa and 40 kPa was about 2.5 g, 3.5 g and 5.9 g, respectively. These results also support the potential of the bubble casting manufacturing technique for soft robotic gripper production. However, studies in the literature have shown that pneumatic grippers can carry objects in the range of kg (Boley et al., 2019). The reason for this situation may be that high air pressures cannot be applied to the produced robotic gripper.

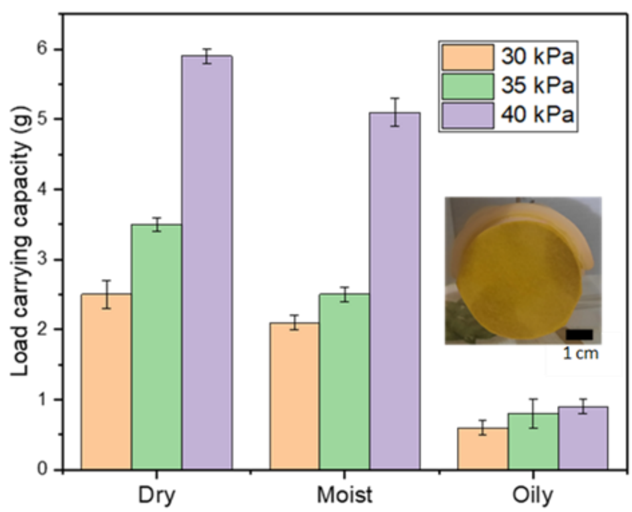

Figure 5. The load-carrying capacity of the gripper as a function of air pressure applied under different environments.

To evaluate the durability of the fabricated grippers, additional tests were conducted. The grippers were grasped to the samples and subjected to repeatable gripping and releasing cycles at varied pressures under dry conditions. Over 100 cycles, the grippers continued to function without noticeably reducing their load-carrying capacity or response time (Figure 6 and Figure 7).

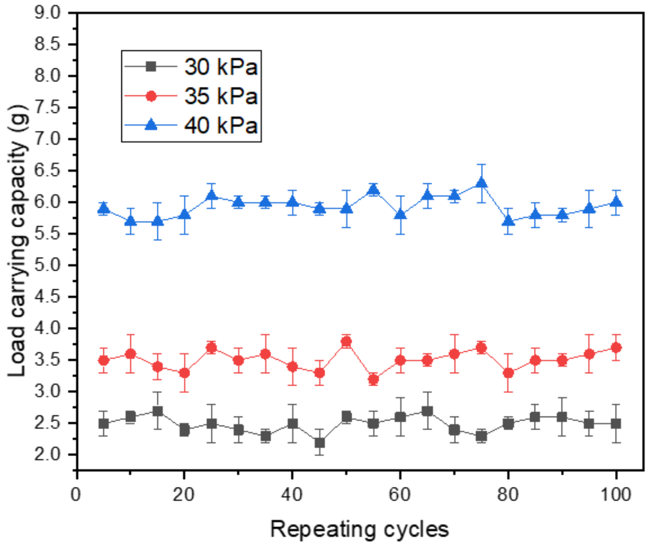

Figure 6. The repeatable load-carrying capacity of the gripper after more than 100 times cycles of gripping and releasing at varied pressures under dry conditions.

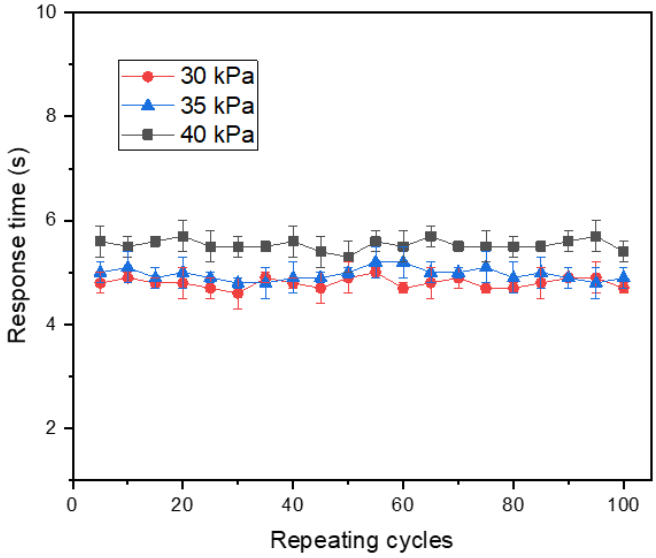

Figure 7. Repeatable response time of the gripper after more than 100 times cycles of gripping and releasing at varied pressures under dry conditions.

4. Conclusions

A new soft robotic gripper that uses compressed air to grasp is prepared by bubble casting technology. Investigations were done into how the liquid elastomer's viscosity affected how the robotic gripper bent. In addition, the curvature, response time and load-carrying capacity of the gripper were evaluated, along with the relation between air pressure was investigated. By adjusting the waiting time, the elastomer's viscosity could be managed. The ideal waiting period was found to be between 3 and 4 minutes for optimal bending performance. In a dry environment, the gripper's load-carrying capability was roughly 2.5 g, 3.5 g, and 5.9 g at pressures of 30 kPa, 35 kPa, and 40 kPa, respectively. The curvature, which increased as the amount of applied air pressure increased, reached its highest value of % 72 when 40 kPa pressure was reached. Furthermore, in comparison to 30 kPa and 35 kPa pressure, the robotic gripper responded more quickly to pressure applied at 40 kPa. As well, for all environments (dry, moist and oily), the gripper's load-carrying capacity increased increasing air pressure up to 40 kPa. These results show that the response time, curvature and load-carrying capacity of the gripper increase as the amount of air pressure being applied rises. Additionally, the gripper's highest load-carrying capacity at all pressures was seen in a dry environment. The soft robotic gripper will be appropriate for practical applications if it is optimized to achieve higher performance.

Author contribution

Murat EROĞLU made this manuscript and did the research.

Declaration of ethical code

This paper does not report research that requires ethical approval. Consent to participate or consent to publish statements are accordingly also not required.

Conflicts of interest

The corresponding author states that there is no confict of interest.

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