2022 IEEE 5th International Conference on Soft Robotics (RoboSoft)
April 4-8, 2022, Edinburgh, UK

OobSoft Gripper: A reconfigurable soft gripper using Oobleck for versatile and delicate grasping.

Francisco Yumbla[1,2], Wendy Yumbla[2], Emiliano Quiñones Yumbla[3] and Hyungpil Moon[4]

***Abstract*— Grasping and holding objects are essential tasks for robotic manipulators. However, the development of universal grippers capable of manipulating unknown objects with widely varying shapes and surface properties remains a challenge. To address this, we present a novel reconfigurable soft gripper (OobSoft) based on Oobleck, deposited on a rubber membrane with a two-finger configuration with an actuation mechanism. This article presents a prototype and the development of this soft gripper with grasping and holding capabilities enabled by a simple actuation mechanism. This objective was achieved by taking advantage of a combination of soft materials, including the properties of Oobleck, rubber, and a bio-inspired design. When pressed on a target object, the fingers (Oobleck inside a rubber membrane) flow around the object and conform to its shape. Upon application of the actuation mechanism, the viscosity of the Oobleck increases, so it quickly hardens to pinch and hold the object without requiring sensory feedback. The development of the soft gripper is explained by the characteristics of the Oobleck and the prototype. The design of the soft gripper involved the anthropomorphic approach used in the design of the fingers. The results of grasping objects and the ability to hold them in position were demonstrated through experimental tests.**

***Index Terms*— Soft Robot Materials and Design, Soft Robot Applications, Soft gripper, Oobleck, Reconfigurable Gripper**

2022 IEEE 5th International Conference on Soft Robotics (RoboSoft) | 978-1-6654-0828-8/22/$31.00 ©2022 IEEE | DOI: 10.1109/ROBOSOFT54090.2022.9762097

Fig. 1. OobSoft Gripper.

I. INTRODUCTION

Grasping and manipulation are fundamental functions of both humans and robots. A simplified description of grasping is the ability to lift and hold an object against external disturbances. Simultaneously, manipulation is the ability to exert forces on an object and thus cause it to rotate and shift relative to the manipulator's frame of reference [1]. Developing devices capable of performing effective object gripping tasks remains a challenging topic that the robotics community has extensively researched [2]. Tasks that seem simple to humans, such as picking up or manipulating objects of different shapes and constructs, can be extremely difficult for robots. Secure grasping between the finger contacts and the object is needed to avoid possible detachment or slippage while the object is being grasped or in transit.

Slippage can be prevented by friction generated by the contact pressure between the two parts (fingers and objects) or by taking advantage of the geometrical constraints of objects to prevent this slippage, such as placing the fingers around the corners or bumps of an object, or the handle of a one-cup bowl. For reliable robotic grasping, the standard design approach relies on a hand with two or more fingers [3], [4]. In [5], [6], in-hand manipulation, robotic hands with multiple degrees of freedom (from simple industrial grippers to fully actuated anthropomorphic robotic hands) were studied and generally involved a combination of visual feedback and a sense of fingertip strength. Many optimization schemes for finger placement and compatible materials have been proposed for adaptive gripping [7], [8], [9], [10].

Several examples of soft grippers for manipulating objects have been developed. Techniques such as cable activation [11], [12], fluid activation [13], the fin ray effect [14], [15], controlled adhesion [16], and controlled stiffness [17], [18] are employed to develop these grippers. A controlled stiffness gripper takes advantage of the large change in stiffness of some materials or material combinations to hold an object. The general method consists of placing the structure of the clamp in its "soft" configuration, approaching and wrapping

[1]Robotics Engineering Research Center, Sungkyunkwan University, 2066 Seobu-ro, Jangan-gu, Suwon, Republic of Korea fryumbla@espol.edu.ec
[2]Faculty of Mechanical and Production Sciences Engineering, ESPOL Polytechnic University, Campus Gustavo Galindo Km 30.5 Vía Perimetral, Guayaquil, Ecuador
[3]School for Engineering of Matter, Transport and Energy, Arizona State University, Tempe, AZ 85287, USA
[4]Department of Mechanical Engineering, Sungkyunkwan University, 2066 Seobu-ro, Jangan-gu, Suwon, Republic of Korea hyungpil@skku.edu

the object to be grasped, and stiffening the structure to hold it through the cage. This method can result in high clamping forces with minimal compression applied to the object. Additionally, grasping strategies can be expanded by using the local stiffness of the structure, allowing for multi-degree-of-freedom shape change with a single actuation input [19].

Soft materials and components continue to be studied for the design of grippers that are lighter, simpler, easier to build and replicate, and conceivably more universal for an infinite number of objects. The importance of safe grasping compliance has long been recognized as a fundamental feature in gripper design. Unless carefully controlled, the contact between a hard clamp and a hard object causes bumps that can damage the object or push it out of the way. A simple but only partial solution for this application, widely used in robotic end-effectors, is to add compatible materials to the structure fingers; for example, adding rubber pads at the end contacts of the end effectors that come into contact with the object. In this case, a rubber is included that would cause soft and secure grasping due to the characteristics of the rubber [1].

The materials used to manufacture soft grippers play a key role. Material characteristics, such as maximum elastic deformation, stiffness, and viscoelasticity, influence the characteristics of soft grippers, the force they can generate, and their response time. Therefore, material selection and engineering are critical for the design of soft grippers with enhanced performance. In this study, we propose a novel soft gripper using Oobleck as the principal material for its development. It is a reconfigurable soft gripper called OobSoft (Fig. 1) that can achieve a delicate yet firm grip on common and simple objects through the synergy of three components: Oobleck, rubber membrane, and actuating mechanism. The following sections of this paper discuss the properties of the non-Newtonian fluid Oobleck. Subsequently, the design of the OobSoft gripper, manufacturing prototype process, and grasping ability demonstrations are presented. In the final sections, we summarize the experimental tests, conclusions and propose future works to improve the prototype.

II. NON NEWTONIAN FLUID: OOBLECK

As early as the 17th century, Sir Isaac Newton described how liquids behave; they all have a constant viscosity, which means that the behavior changes as a function of temperature and pressure. However, it has been found that some fluids do not follow these basic rules, hence the name non-Newtonian [20]. Newtonian fluids change their viscosity under sudden stress, and this change can change the thickness of the fluid . There are several types of non-Newtonian fluids [21]. Dilatant and pseudoplastic fluids have in common that their viscosities change under stress (for a short period). When the force is removed, their viscosities return to their normal values. The dilatant is shear-thickened, which means that when a force is applied, the viscosity of the fluid immediately increases; e.g., Oobleck, which is the subject of the test presented in this article. Pseudoplastics are the opposite of shear-thinning dilatant fluids.

Fig. 2. Depicting Oobleck Free Fall.

Oobleck is an inexpensive and non-toxic example of a non-Newtonian fluid, which is a suspension of starch in water, occasionally called ooze or magic mud. The name Oobleck was inspired by Dr. Seuss's book Bartholomew, and it exhibits unusual behavior. Because of its sheer thickening properties, a person can walk on a large tub of Oobleck without sinking. Another example of unusual behavior is that if a person punches it or any impact force is applied to it, it acts like a solid. However, when a gradual load is applied, it behaves like a liquid [22]. The basic recipe for this liquid is corn starch and water in a ratio of two to one cup (1 part water to 1.5–2 parts corn starch) [23]. The small particles of corn starch repel each other slightly, causing the liquid to flow normally; however, when a sudden force is applied, the small force of repulsion is overpowered, and the particles stick together, causing the liquid to harden. As the force dissipates, the particles repel each other, and the fluid flows again [24].

Oobleck is a suspension of starch in water. Instead of dissolving in water, starch grains remain intact. When an impact load is applied, starch grains lock into position because they rub against each other. This phenomenon is known as shear thickening and occurs in materials composed of microscopic solid particles suspended in a fluid. Two theories have been proposed to explain this phenomenon. First, friction between the solid particles locks them in their configuration and causes them to resists flow. Second, as the particles approach each other, the resistance to drain the liquid between them slows their movement and locks the particles into groups [25]. In the Oobleck fluid, particles in a dense suspension resist additional compression in the shear direction. At rest, the starch grains are surrounded by water droplets due to the high surface tension of water. The grains flow freely as the water acts as a lubricant, facilitating the flow of the starch grains. When an impact load is applied, the force pushes the water out of the suspension, and the starch grains entwine with each other.

In Oobleck, the long chains are composed of large solid corn starch molecules. The water molecules flow slightly between the corn starch molecules, allowing them to flow easily. Thus, Oobleck behaves like a liquid in a state of rest or when a gradual load is applied. A fascinating aspect of Oobleck is the ambiguity of whether it is a liquid or solid. Because of its properties, Oobleck is often used for demonstrations that exhibit unusual behaviors related to its viscosity. Viscosity is a measure of the strength with which fluid layers resist flowing over each other under stress or shear forces. It becomes more viscous when a shear force is applied and behaves like a solid. When the force is removed, it acts as a fluid [26].

III. PROTOTYPE FABRICATION OF OOBSOFT GRIPPER

Soft robotics exploits the compliance and flexibility of materials to create manipulators that are highly configurable, adaptable, and allow safe interactions with the objects to be manipulated and the environment. The choice of materials and manufacturing techniques used in construction is key to developing smooth manipulators for common use or for industrial spaces. Soft robotics leaves room for inspiration and creativity in design and manufacturing methods, which are infinite by eliminating the common principles and rules followed in rigid robot design. Soft robotics also uses fast and adaptable manufacturing techniques that allow for a rapid design and test cycle, which are often necessary because it can be difficult to fully model and predict their behavior.

For the design of the OobSoft gripper, we relied on a device called the universal soft gripper, developed by Brown et al. [18]. It contains coffee grounds deposited on a latex rubber membrane subjected to pressure changes when air is introduced or extracted. The high elasticity of the ground coffee-filled bag conforms to the object, and the evacuation of air provides sufficient rigidity to hold and lift the bag. The change in stiffness of the bag is a consequence of the change in pressure between the granules [27]. Depressurization of the bag filled with loose granules produces compressive forces between the granules, which limit their physical movements, causing the entire bag to behave as a single, solid object. Air injection into the rubber membrane returns it to a soft state because the granules move freely with a behavior similar to that of a liquid. The mechanism underlying this phenomenon is called granular interference or granular transition [28]. This phenomenon is identical to the characteristics observed in Oobleck regarding the behavior of cornstarch particles in contact with water. The disadvantage of the universal soft gripper is that the dimensions of the coffee beans can vary, and at the moment of extracting the air, the positions of the coffee beans could not be uniform like rocks stacked on a wall. Therefore, the contact of the clamp with the object's surface may have empty spaces. This means loss of points of contact for which loss of grip

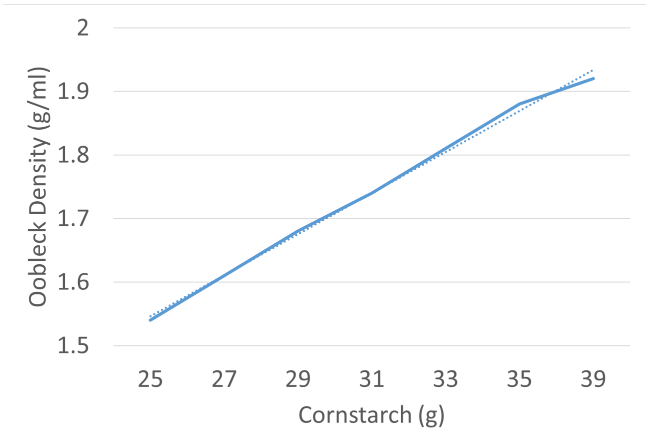

Fig. 3. Density test: The Oobleck with the original formula is only increased by two grams of cornstarch to calculate its density and obtain more viscosity for tests with the soft gripper.

Fig. 4. Four different Oobleck formulas start from less cornstarch to high, without changing the percentage of water in the first formula. The pictures show how the Oobleck increased their density and viscosity.

strength. So, the gripper risks not having a stable grip on the object and losing it in the manipulation.

Therefore, after analyzing the characteristics of Oobleck in terms of density and viscosity. At the same time, the particles have the same dimensions in which they would adapt more to the grasped object. In this work, we present a novelty prototype of a soft clamp whose main material used to hold objects will be a rubber membrane containing Oobleck (water and corn starch). The following section presents the analysis of densities, the manufacture, and the selection of the most efficient combination of the Oobleck for our purpose, which is to have a soft gripper to have a firm and precise grip of objects. We focus on three main aspects of the gripper's design: the soft structure, the reconfiguration of the fingers, and the mechanism for the actuation.

It was decided to deposit the Oobleck inside a rubber membrane for the soft structure and the ability to reconfigure the fingers. The Oobleck can be moved thru and fill all the spaces of the rubber membrane that contains it also has the properties of changing its viscosity. The rubber membrane can be redesigned according to the needs of the objects about the dimensions that we must manipulate. In this article, the shape was selected to be two little fingers. As soon as the Oobleck comes into contact with the rubber membrane, it disperses everywhere and maintains its shape, waiting for some change or pressure to solidify momentarily. The membrane helps to the adhesion of the objects and helps to spread the Oobleck around the object grasping position. The density was determined and calculated to determine the formula of the Oobleck (percent of starch and water), or the most optimal one so that it acts more optimally with the rubber membrane. In parallel, the viscosity was visually and experimentally analyzed with the behavior of the gripper in the process of object grasping.

We start by preparing the most common mixture that everyone uses to make Oobleck, two cups of cornstarch with one cup of water, representing 300 g of cornstarch and 250 g of water, respectively. Materials used: cornstarch, beaker to measure the volume of the prepared Oobleck, scale to measure the weight of the percentages of water and cornstarch used. A twelve percent of the original mixture is made, equivalent to 25 g of cornstarch and 20.75 g of water. With this mixture, we began to increase by two grams of corn starch because with more corn starch, the density and viscosity increased, the density calculation was made, and the results are shown in Fig. 3 A visual comparison is made of the viscosity that increases about the increase in the proportion of cornstarch used. It is shown in Fig. 4 four formulas with different densities and viscosities; it is appreciated how the Oobleck in free fall has different behaviors due to the increase of cornstarch in its formula.

The rubber membrane was filled with different densities to determine the Oobleck optimal concentration about of corn starch in our soft gripper, and tests were carried out to see how it reacted to the solidification of the same while it was in contact with an object, it was determined that the higher the density, the Oobleck requires less impact force to solidify and the time to come back to liquid is slower. However, it must have a percentage of water for it to return to its initial settings. The most suitable combination was chosen to be a combination of 64 g of cornstarch and 41.5 g of water in the grip and fixation tests that will be explained in the next section.

For the actuator mechanism, because the Oobleck as described by its nature, we need to cause forces that act on the rubber membrane, which in turn acts on the Oobleck, causing it to solidify for a time in the way we want, so A simple 3D printed design was developed as shown in the Fig. 5. The mechanism consists of two parts, a fixed elastic TPU structure (red color) that adheres to the rubber membrane that contains the Oobleck, performing a parallel force between

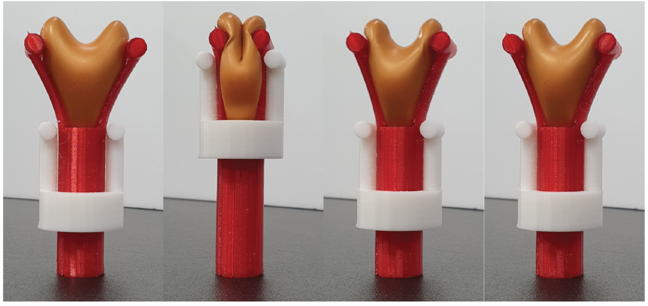

Fig. 5. OobSoft gripper parts are Oobleck inside a rubber membrane (gold color) and the actuator mechanism, it is a red elastic structure (TPU material), and a white rigid structure (PLA material) which slides over the elastic structure to produce the forces for the Oobleck solidification.

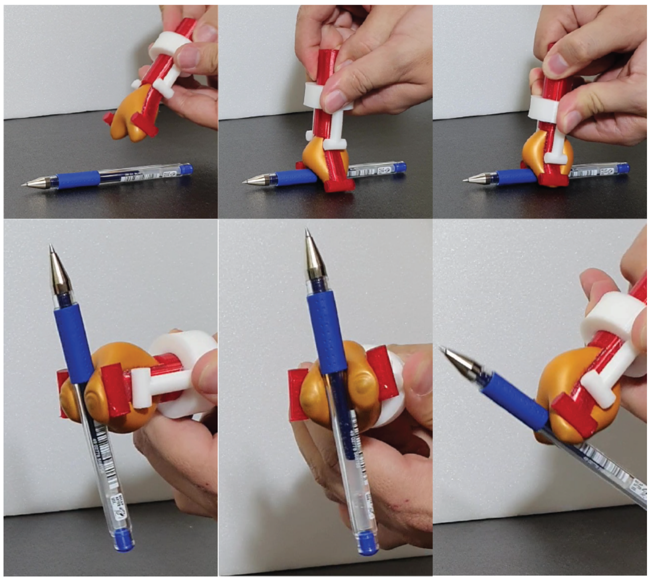

Fig. 6. Manipulation experiment consists are grasping and manipulation of a pen. The rubber membrane with the Oobleck flows around the pen and adjusts to its shape; after that step, the actuator mechanisms act to produce the force that makes the Oobleck solidify for the OobSoft gripper to obtain a successfully grasping.

the fingers of the rubber membrane, and a rigid mobile structure that is printed with the PLA material to serve as force and speed propagator so that the gripper can act (white color). The Fig. 5 shows how the actuation mechanism works to perform the gripping process. First, the initial state is that the elastic structure (red color) is open due to the pressure of the Oobleck inside the rubber membrane. The Oobleck is in a liquid state with low viscosity. Then the rigid structure (white color) slides through the flexible structure to produce the necessary force that makes the Oobleck solidify, so the rubber membrane maintains the grasping form around a certain time and maintains its shape until again the rigid structure returns and disengages. Finally, it can be seen how the elastic structure with the Oobleck returns to its initial configuration to perform the same process again. We must be clear that the solidification of the Oobleck is for a certain time by starting with the mechanism actuator. The viscosity is lost due to the lack of the action of the part of the

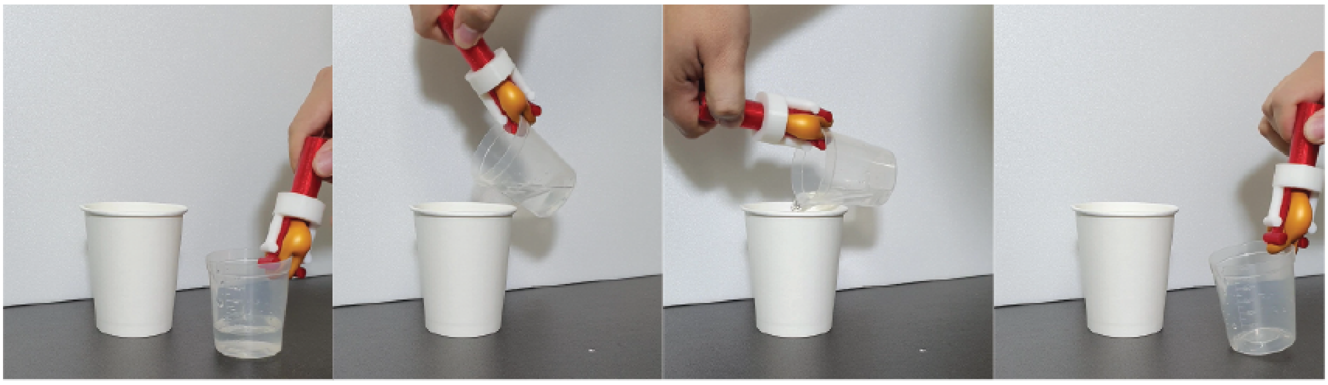

Fig. 7. Manipulation test consists of a container with water grasping by our OobSoft gripper to deposit its content inside the other.

mechanism to the rubber membrane. The times that we have found for this Obleck mixture are to maintain solidification for a time of eight seconds then it returns to its liquid state, this is a limitation on our clamp.

IV. EXPERIMENTAL TESTS

In accordance with the main objective of the present work, stable grip and smooth interaction with the target object have been investigated. Two types of experimental tests have been performed t o evaluate these aspects. The first test is related to the ability of the soft forceps to grasp and hold objects of different sizes and shapes; the second test aims to quantify the grasping force to be able to lift objects. The expected results of the proposed experimentation are strictly related to the demonstration of two basic concepts: how Oobleck works within the rubber membrane for finger/object interaction and in combination with the actuation mechanism to generate stable adaptive grasping. For the testing process, grip tests were performed on objects within the design capabilities of our gripper, which could only grip a certain area within the fingers.

Grasping posture refers to the gripper's ability to adapt its fingers to the shape of the target object. The experiment was performed using the following procedure. The first step was to press the soft gripper on the object. The rubber membrane with Oobleck flows around it and adjusts to its shape. Next, the actuation mechanism solidifies the Oobleck by sliding the rigid structure (white-colored PLA) through the elastic structure (red-colored TPU) to produce a force in the rubber membrane that causes the gripper to solidify when the Oobleck maintains a firm grip on the object. At this moment, the object can be lifted. The rubber membrane with Oobleck gripped the object firmly, and it appears that the fingers were crushed by the pressure placed on the flat surface table. To release the object, the rigid structure (white PLA material) of the elastic structure (red TPU material) slid on the opposite side, and the gripper returned to its original position and shape, ready to repeat the grasping process . Human control was used in the loop, in which an operator adjusted and controlled the actuator mechanism to achieve a proper clamping configuration with the grasped object. In a future version, the process will be automated using linear motors that will perform the process. Different everyday objects varying in size, shape, and material are gripped. A pen was selected in one of the grasping and manipulation experiments. The full manipulation process is described in Fig. 6.

As determined in the previous section, our OobSoft gripper acts in a given time of eight seconds. The membrane adhesion to the object is maintained by the Oobleck solidify and be lost after eight seconds when the Oobleck returns to its liquid state, as shown in figure 6. The image on the left shows that the rubber membrane is plane because of the Oobleck's contact force, solidifying the table. In the middle one, we can see how the Oobleck begins to lose its solidification, so the transport of the object must already be finished at that moment with the right picture. All these aspects should be improved to have more extended Oobleck solidification times. This can be achieved when the forces against the membrane are repetitive. We tried a vibration motor adapted to keep the Oobleck solidifying active without success. Nevertheless, the force produced was weak, so this paper did not include the solution.

In terms of the smoothness of the OobSoft gripper, the materials play a central role in the interaction between the object and the finger, which also correlates with the nature of the contact in terms of the object forces. The rubber membrane adhesion and gripping force were also tested using flat surfaces, as shown in Fig. 7. The experimental test consists of manipulating the container with water to deposit its content inside the other, which is usual today. The soft forceps again perform the object grasping procedure. The clamp lifts the object with the help of the Oobleck pressing the two surfaces, and the rubber membrane helps to prevent the container from slipping and helps to finish handling, lifting, and pouring the contents while the rubber membrane system continues to act with the Oobleck with the actuation mechanism to have a successful process. In this test, we also have the limitation of the time in which the Oobleck remains solidified, so the whole process takes eight seconds between grasping the cup, depositing the water, and returning the empty cup to its position.

V. CONCLUSIONS AND FUTURE WORKS

This work presents the design and characterization of a new clamp: the ReSoft clamp. The design combines the following characteristics: the soft structure, the reconfiguration of the fingers, and the actuation mechanism. Using a rubber membrane as a material helps grasp an unevenly textured object. The Oobleck works with the rubber membrane to reconfigure the fingers and thus the process of grasping the objects. The actuation mechanism allows the viscosity of the Oobleck to be changed at the moment of producing a force, for which, with the rubber membrane, they adapt to the object's geometry and provide a firm grasping. Our experiments tests demonstrated that the combination of reconfiguration thanks to the Oobleck and actuator mechanisms allows the gripper to grasp certain geometries of objects and hold precise. The prototype was manufactured using a rubber membrane shaped like little fingers, and the actuator mechanism was 3D printed using TPU and PLA filaments. We hope that the design and demonstrations of the OobSoft Gripper will provide a cost-effective, lightweight, alternative solution to object handling challenges. Future work plans to carry out improving the prototype and do more tests with other scenarios and objects due to we have some limitations of this gripper: the grasping area and the grasping object time. The rubber membrane must be resized and reshaped if larger objects need to be gripped. The fingers could be longer with more thick and thin segments would improve the maximum grasping size limit. Redesigning the actuation mechanism, we will include motors and active actuators will help to maintain the Oobleck solidification for extending the grasping object time.

ACKNOWLEDGMENT

This work was supported by the National Research Foundation of Korea(NRF) grant funded by the Korea government(MSIT) (No. 2020R1A4A1018227).

REFERENCES

[1] J. Shintake, V. Cacucciolo, D. Floreano, and H. Shea, "Soft robotic grippers," *Advanced Materials*, vol. 30, 7 2018.

[2] M. Manti, T. Hassan, G. Passetti, N. D'Elia, C. Laschi, and M. Cianchetti, "A bioinspired soft robotic gripper for adaptable and effective grasping," *Soft Robotics*, vol. 2, pp. 107–116, 9 2015.

[3] M. T. Mason and J. K. Salisbury, *Robot hands and the mechanics of manipulation*. MIT Press, 1985.

[4] D. T. PHAM and S. H. YEO, "Strategies for gripper design and selection in robotic assembly," *http://dx.doi.org/10.1080/00207549108930072*, vol. 29, pp. 303–316, 2007.

[5] G. J. Monkman, S. Hesse, R. Steinmann, and H. Schunk, *Robot Grippers*. WILEY-VCH, 2007.

[6] A. M. engineer) Wolf, R. Steinmann, and H. Schunk, *Grippers in motion : the fascination of automated handling tasks*. Springer, 2005.

[7] W. S. Howard and V. Kumar, "On the stability of grasped objects," *IEEE Transactions on Robotics and Automation*, vol. 12, pp. 904–917, 1996.

[8] Y. C. Park and G. P. Starr, "Grasp synthesis of polygonal objects using a three-fingered robot hand:," *http://dx.doi.org/10.1177/027836499201100301*, vol. 11, pp. 163–184, 7 2016.

[9] M. R. Cutkosky and P. K. Wright, "Friction, stability and the design of robotic fingers:," *http://dx.doi.org/10.1177/027836498600500402*, vol. 5, pp. 20–37, 7 2016.

[10] T. Yoshikawa and K. Nagai, "Manipulating and grasping forces in manipulation by multifingered robot hands," *IEEE Transactions on Robotics and Automation*, vol. 7, pp. 67–77, 1991.

[11] I. Hussain, M. Malvezzi, D. Gan, Z. Iqbal, L. Seneviratne, D. Prattichizzo, and F. Renda, "Compliant gripper design, prototyping, and modeling using screw theory formulation," *International Journal of Robotics Research*, vol. 40, pp. 55–71, 1 2021.

[12] G. Salvietti, I. Hussain, M. Malvezzi, and D. Prattichizzo, "Design of the passive joints of underactuated modular soft hands for fingertip trajectory tracking," *IEEE Robotics and Automation Letters*, vol. 2, pp. 2008–2015, 10 2017.

[13] Z. Wang, Y. Torigoe, and S. Hirai, "A prestressed soft gripper: Design, modeling, fabrication, and tests for food handling," *IEEE Robotics and Automation Letters*, vol. 2, pp. 1909–1916, 10 2017.

[14] K. Elgeneidy, P. Lightbody, S. Pearson, and G. Neumann, "Characterising 3d-printed soft fin ray robotic fingers with layer jamming capability for delicate grasping," *RoboSoft 2019 - 2019 IEEE International Conference on Soft Robotics*, pp. 143–148, 5 2019.

[15] K. Elgeneidy, A. Fansa, I. Hussain, and K. Goher, "Structural optimization of adaptive soft fin ray fingers with variable stiffening capability," *2020 3rd IEEE International Conference on Soft Robotics, RoboSoft 2020*, pp. 779–784, 5 2020.

[16] J. Shintake, S. Rosset, B. Schubert, D. Floreano, and H. Shea, "Versatile soft grippers with intrinsic electroadhesion based on multifunctional polymer actuators," *Advanced Materials*, vol. 28, pp. 231–238, 1 2016.

[17] J. R. Amend, E. Brown, N. Rodenberg, H. M. Jaeger, and H. Lipson, "A positive pressure universal gripper based on the jamming of granular material," *IEEE Transactions on Robotics*, vol. 28, pp. 341–350, 4 2012.

[18] E. Brown, N. Rodenberg, J. Amend, A. Mozeika, E. Steltz, M. R. Zakin, H. Lipson, and H. M. Jaeger, "Universal robotic gripper based on the jamming of granular material," *Proceedings of the National Academy of Sciences of the United States of America*, vol. 107, pp. 18 809–18 814, 11 2010.

[19] Y. Li, Y. Chen, and Y. Li, "Distributed design of passive particle jamming based soft grippers," *2018 IEEE International Conference on Soft Robotics, RoboSoft 2018*, pp. 547–552, 7 2018.

[20] R. P. Chhabra, "Non-newtonian fluids: An introduction," *Rheology of Complex Fluids*, pp. 3–34, 2010.

[21] S. Patel and R. Chhabra, "Non-newtonian fluids," *Kirk-Othmer Encyclopedia of Chemical Technology*, pp. 1–49, 9 2020.

[22] V. S. R. Krishna, S. Hussain, C. H. Kiran, and K. V. Kumar, "Experimental evaluation of impact energy on oobleck material (non-newtonian fluid)," *Materials Today: Proceedings*, vol. 45, pp. 3609–3617, 1 2021.

[23] B. Bahr, B. Lemmer, and R. Piccolo, "Non-newtonian fluid," *Quirky Quarks*, pp. 38–41, 2016.

[24] H. N. Soundararajan, E. Agustsson, R. A. D. Martinez, A. Westergren, and J. L. G.-C. Pérez, "Usage of oobleck as a packaging material," *International Journal of Scientific and Research Publications*, vol. 3, 2013.

[25] M. A. Rao, *Rheology of Fluid and Semisolid Foods*. Springer US, 2007.

[26] R. Chhabra and J. F. Richardson, *Non-Newtonian flow in the process industries : fundamentals and engineering applications*. Butterworth-Heinemann, 1999.

[27] H. M. Jaeger, "Celebrating soft matter's 10th anniversary: Toward jamming by design," *Soft Matter*, vol. 11, pp. 12–27, 12 2014.

[28] A. J. Loeve, O. S. van de Ven, J. G. Vogel, P. Breedveld, and J. Dankelman, "Vacuum packed particles as flexible endoscope guides with controllable rigidity," *Granular Matter 2010 12:6*, vol. 12, pp. 543–554, 6 2010.