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Research Paper

Comparing the Performance of Composite Polymer Structure and Single Polymer Material by Manufacturing Artificial Hand using 3D Printing Method

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Abstract

A composite structure is a non-uniform solid that consists of two or more different materials with different kinds mechanically bonded together. Compared to their components, these structures have superior properties (such as high strength and flexibility, incredible softness, etc.). They can be designed according to the needs, and different mechanical properties can be achieved. In this article, to prove the superiority of composite structures over single material structures, two products, including an articulated hand (single material) and a flexible hand (composite material), have been designed and manufactured using 3D printing technology (incremental layering). To investigate the performance of these two hands, the bending angles of the fingers of each hand in the open and closed state at different times were measured by the protractor. They were eventually compared, analyzed, and evaluated. The results of this study indicate that due to the use of composite material, the flexi fingers can easily bend and straighten up to 100 degrees in 2.8 seconds. Still, the articulated hand repeats this movement in 3.3 seconds. These results indicate that the flexi hand repeats the movement of the human hand faster due to its high flexibility.

Keywords

3D Printer, Composite Material, Artificial Hand, ABS, TPU

1. Introduction

The use of natural or synthetic materials to replace or integrate body functions or organs damaged by traumatic or pathologic events to assist tissue healing or correct abnormalities dates far back to the beginning of medicine in ancient civilizations. Therapeutic innovations and the design and implementation of complex medical devices allow increased patient survival, significantly improve quality of life, and contribute to life expectancy increment.

From gross movements to object grasping and fine manipulation, our arms and, specifically, our hands play a valuable role in our daily lives. Losing a limb presents a difficult challenge in that much of the

basic functionality we rely on as humans is no longer available in the same way. Using prosthetic hands has proven to be a viable option for replacing a lost or missing hand [1].
The importance of applying an artificial hand is influenced by its various applications in daily life. Regardless of the cosmetic results, the patient can perform his work and leisure duties better with this treatment. Most artificial hand prostheses are designed to simulate the missing limb, and it is possible to perform daily activities with them. Therefore, artificial hands should closely resemble the natural human hand.
Polymers, including thermoplastic and thermoset materials, are the most common materials used to construct robots and artificial hands. Among these polymers, we can mention ABS (Acrylonitrile Butadiene Styrene), TPU (Thermoplastic Polyurethane), PLA (Polylactic Acid), etc.
Since the organs of all living creatures have the structure of composite materials, the combination of hard and soft polymer materials makes it possible to design the desired structure according to the needs and obtain a behavior close to the behavior of the actual organ. Therefore, in this article, we combined two non-homogeneous hard (ABS) and soft (TPU) polymer materials to make an artificial hand that can simulate and repeat the movement of the human hand to a large extent. In addition, to compare the performance of this hand, a single-material hand (from ABS material) was made, and the composite property compared to a single-material hand was measured.
Much research has been done in composite materials, artificial hand manufacturing, and performance optimization, among which some investigated the construction of composite structures consisting of hard and soft materials by 3D printing methods in robots [2-7]. Some researchers worked on manufacturing prostheses, artificial hand-fingers from composite materials by 3D printing [8-15], which replace the patient's hand. In the following, we will review some of these articles.
In 2018, Jahan Zeb Gul et al. [2] reviewed 3D printing processes and materials for soft robotics. In research, an integrated construction of composite structures consisting of hard and soft materials using a 3D printing method was investigated in robots [3]. Furthermore, Mikal Soreni-Harari et al. [4] studied the microrobot mechanisms made by 3D printing, and Arvind Ananthanarayanan et al. [5] made the structures of a miniature snake robot with soft joints using 3D printing. A new 3D printed multi-material design for a robotic hand was proposed, which addresses two challenges: 1-the ability to control the stiffness and 2-the ability to control the bending position in soft pneumatic clamps [6]. A soft robotic hand was also proposed in the article [7], which consists of soft actuator cores and a hard exoskeleton. The proposed design has a multi-material mechanism presented with the help of Finite Element Analysis (FEA) to define the geometry of the hand and improve finger bending.
Yi Ling Yap et al. [8] reviewed 3D printing processes and materials for artificial robot hands. This article aimed to investigate 3D printing processes and flexible materials for soft robotic applications. The filament used in this project is TPU material. These robots can completely catch and hold objects due to their softness.
In 2016, a study was conducted on manufacturing and testing fingers of integrated artificial hands by 3D printing method [9]. This study examined several standard bending hinges, which produced large displacements under the lowest possible input force. This work aimed to design a soft and integrated robotic finger. In this research, the bending of soft integrated robotics was simulated by estimating the effective elastic modulus, which showed a good relation with actual experimental results.

A start-up project was investigated to make an artificial hand by 3D printing using common polymer materials PLA or ABS [10]. The idea of the article was that by combining the designs of similar initiatives abroad and the mechanical design, the artificial hand could be approached with 3D printing. Zhang et al. [11] proposed a system framework for designing and automating multi-material soft robots. A multi-material pneumatic soft finger, modeled as an adaptive mechanism, was optimized to achieve maximum bending deflection and further customized for practical grips, rehabilitation, and artificial hand applications. The results showed that the optimized multi-material fingers could undergo a bending deflection and bear more loads.

The research [12] presents a novel approach to a prosthetic hand, including an alternative flexible 3D-printed hand that enables objects to be taken. This research used a 3D light scanner to produce an alternative hand. The alternative wrist was made of hard materials, and other parts of the hand were made of flexible materials. A standard arm line was also used to activate the user's arm stomp to the alternative hand.

Marcarus et al. [13] developed an artificial hand with complex 3D smart structures using innovative designs and multi-material additive manufacturing technology. The printed hand uses a multi-material layered architecture of ABS, TPU, and PLA to ensure easy printing without any support structure. The fingers are activated through the tendon mechanism. Tendons are stretched through microlinear actuators to achieve finger flexion. After that, the linear actuator is released, and the finger returns to its normal state. The fingers are designed to only have TPU material in the joints, which will return to the original state by changing the elastic shape of the finger after removing the tension force.

In another study [14], a polymer artificial hand was manufactured using a 3D printing technique in which servomotors controlled the opening and closing of the fingers. Two proposed models are given in this article, which finally led to finding a linear relationship between the angles of the fingers of the artificial hand and the human hand.

A low-cost artificial hand using 3D printing is proposed by [15]. In this article, by using piezoresistive sensors connected to the palm, a multi-sensor system is built that can determine the forces on the glove and convert them into a quantity. This system has shown promising results and can be used as a springboard to develop a more complex and multifunctional system.

A lot of work is done in the field of artificial hands. We have mentioned only a few of them here. You can refer to [16-19] to see more.

The rest of the article is organized as follows: The materials and tools used in this article are reviewed in Section 2. In part 3, the article's proposed solution, including the structure of artificial hands and the analysis of finger movement and performance comparison of two hands, are presented, and section 4 includes the article's conclusion.

2. Materials and tools

In this part, all the necessary tools and materials used in this article are explained.

2.1 3D printer

3D printing or additive manufacturing, known as physical simulator in the industry, is a process of making a three-dimensional solid object of virtually any shape from a digital model. Successive layers of material are laid down to construct a customized object. Each layer can be seen as a thinly sliced

horizontal cross-section of the eventual object. The available materials also vary by process. 3D printing enables the production of complex shapes using less material than traditional subtractive manufacturing methods, which involve cutting/ machining out the object from a larger block [20].
The 3D printer makes a three-dimensional solid object from a digital model. It consists of a 3D printing apparatus attached to a multi-axis robotic arm. The arm consists of a nozzle that deposits metal powder or wire on a surface and an energy source (laser, electron beam, or plasma arc) that melts it, forming a solid object [20].
In this research, the Sizan1 3D printer shown in Figure 1 made artificial hand parts.

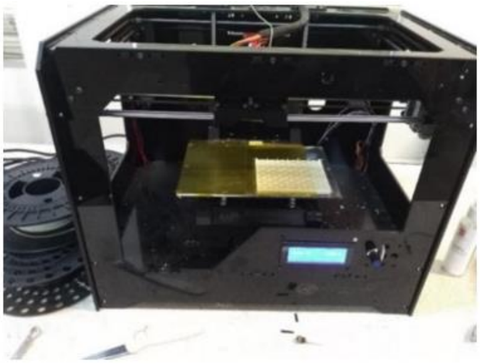

Figure 1. 3D printer Sizan1

2.2 ABS

ABS filament is a part of the family of thermoplastic polymers, which is obtained from the combination of three materials: "Acrylonitrile," "Butadiene," and "Styrene." This thermoplastic is cheap, durable, and lightweight, and it quickly gets out of the extruder, which is why it is very popular for 3D printers. Parts made of ABS filament in the 3D printer have high rigidity and can withstand shocks at low temperatures to some extent.

2.3 TPU

TPU, or polyurethane filament, is a thermoplastic elastomer that is very flexible. This composite material is considered versatile due to its strength and durability. Parts made of TPU filament can be easily bent or stretched without breaking, losing their original shape, and returning to their original state after loading. Some of the unique properties of this material are softness, high strain, etc. [21].

3. Proposed solution

As mentioned above, two types of artificial hands, including a flexi hand and an articulated hand, have been manufactured in this article. Flexi artificial hand's components were made of both ABS and TPU filaments, but the articulated artificial hand was only printed from ABS filament with Kimya brand.
The printing parameters of the 3D printer have been set as follows: the infill of the material was 40%, the layering thickness of the print was 0.2 mm, and the layering angle was set at 45 degrees to the horizontal axis, shown in Figure 2.

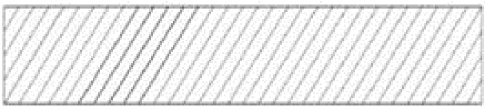

Figure 2. Raster orientation at an angle of 45° [21]

The ABS material was extruded at 240° C, at a speed of 80 mm/s with a heated bed surface of 90° C, and the TPU material was extruded at 250° C and a speed of 30 mm/s having a heated bed surface of 50° C.

3.1 Flexi artificial hand structure

This artificial hand is made of ABS and TPU filaments using 3D printing. The knuckles of this hand are made of ABS, which is a rigid material, and the joints between these knuckles are made of soft and flexible TPU material. The design and manufacture of this hand have been done in such a way that, on the one hand, the knuckles are firm and can hold objects like a human hand. On the other hand, the knuckles can move due to the use of soft and flexible joints, so bending and straightening of the fingers will be possible. A cable was used to move the fingers, and an electric motor with a GA12-N20-6V50 gearbox was applied along with a pulley to move the cable. One side of the cable is fixed with the front part of the finger, and the other is connected to the pulley. The clockwise rotational movement of the pulley causes the cable to be stretched, and the desired finger is bent from the soft joints. By changing the rotation of the pulley in the counterclockwise direction, the cable is loosened, and the finger returns to its original state through elastic joints. The movement of the other fingers is also similar to the procedure above. The function of this artificial hand can be seen in Figure 3. It should be noted that all stages of designing and manufacturing the flexi hand have been done in this article. The design was performed using Solidwork software.

Figure 3. Flexi artificial hand made by 3D printing method

3.2 Articulated artificial hand structure

All parts of the articulated artificial hand are made of ABS filament, a rigid material. The design of this hand, inspired by the human hand, has been done in such a way that each knuckle moves by its lever.

This hand has strong fingers due to the use of ABS material. Each finger of this hand has a separate servomotor and can repeat the movement of an actual human's hand. The servomotor used in this hand is MG90, which moves the finger's lever. The function of the fingers of this hand is as follows: the servomotor moves the main lever, and this lever moves the main knuckle, which leads to the movement of the middle knuckle and then the last finger.

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Figure 4 shows the assembled image of this artificial hand. It should be noted that Youbionic Company carried out the design of this hand, but manufacturing of this hand was completed in this article.

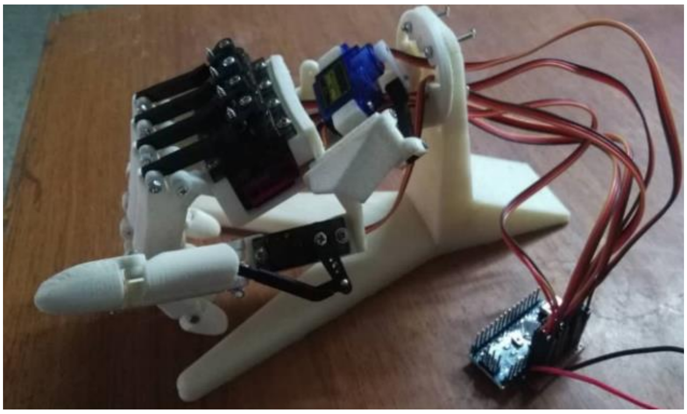


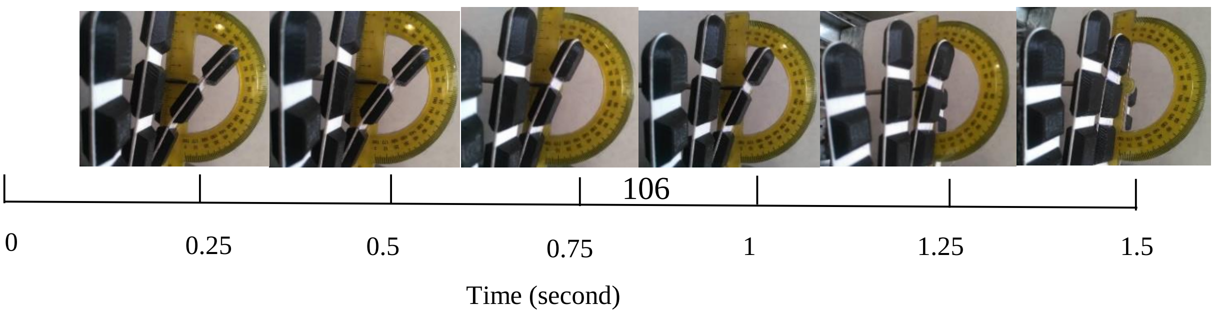
Figure 4. Articulated artificial hand-made by 3D printing method

3.3 Analysis and comparison of both hands

In this analysis, one of the fingers of the flexi hand was compared with the articulated hand in two open and closed states between the interval of 0 to 3.5 seconds by the protractor, and the results are presented as follows.

3.4 Closing state of one finger of both hands

The images related to closing the flexi and articulated hand can be seen in Figures 5 and 6, respectively. The results related to the analysis of the finger of these two hands in the closing state are also given in the diagram of Figure 7.



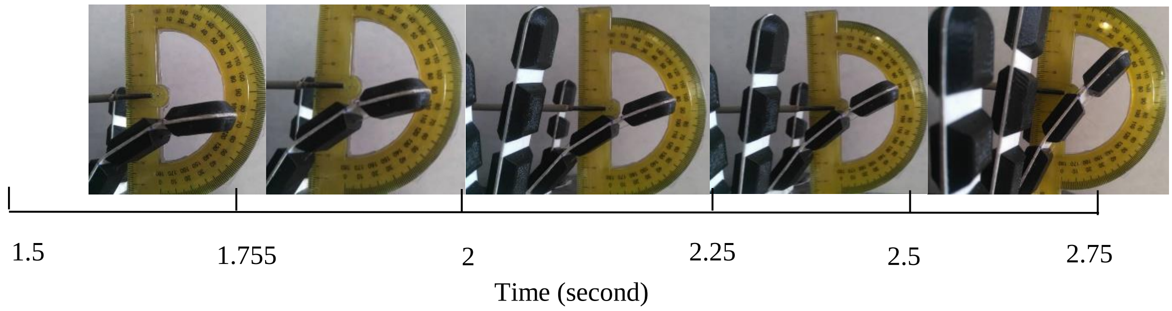


Figure 5. Closing state of the finger of the flexi hand

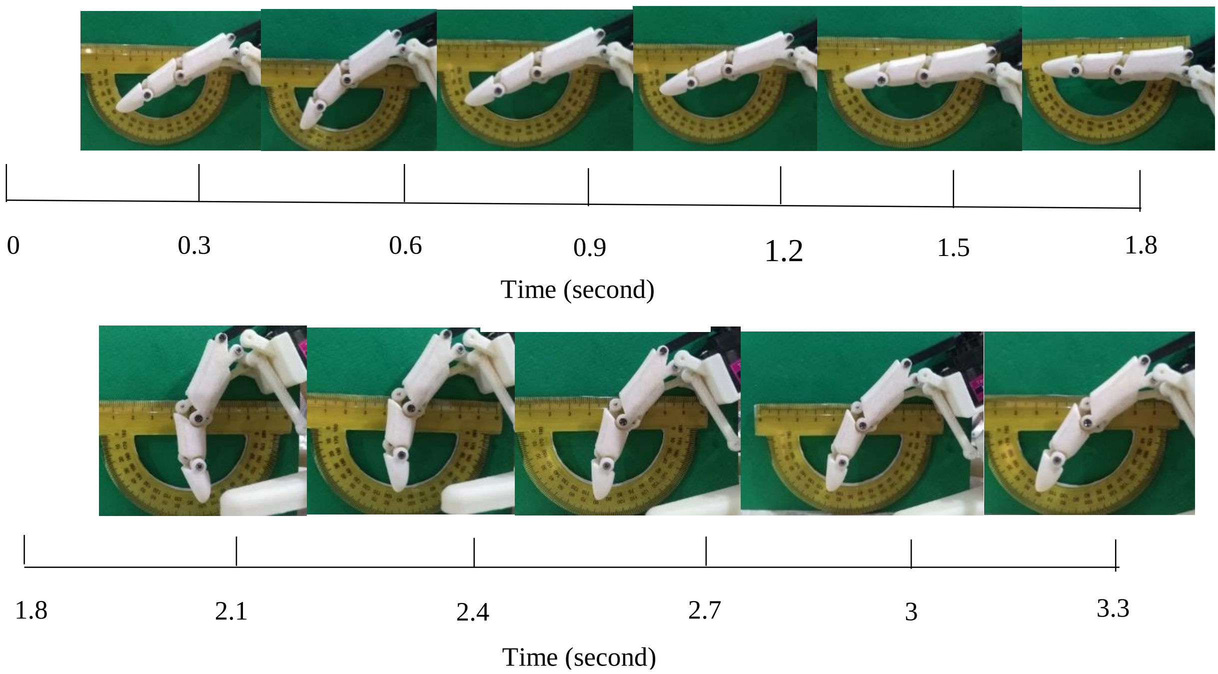


Figure 6. Closing state of the finger of the articulated hand

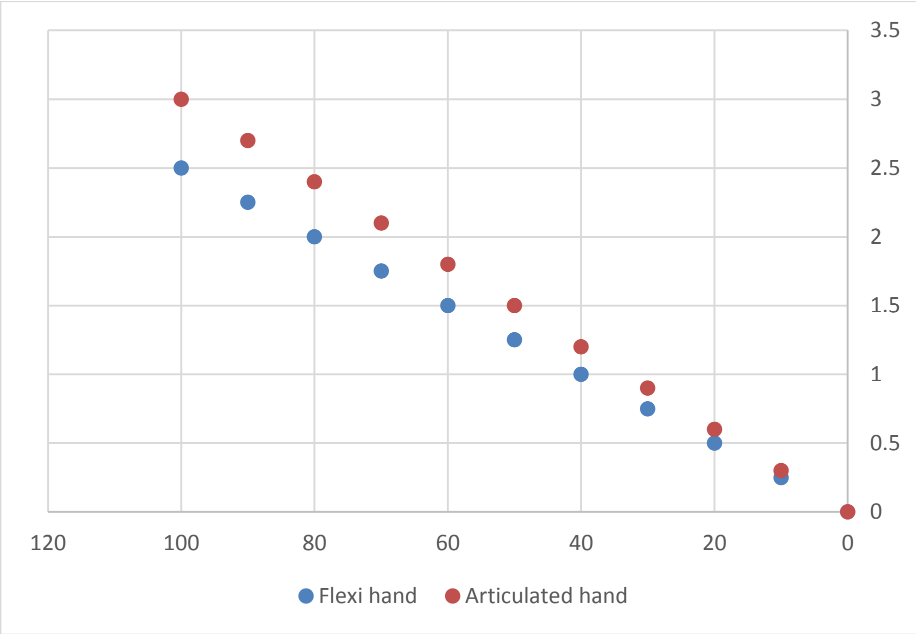


Figure 7. Comparison of the fingers of both hands in the closing state

3.5 Opening state of one finger of both hands

The images related to the opening state of the finger of the flexi and articulated hand can be seen in Figures 8 and 9, respectively. The results related to the analysis of the finger of these two hands in the opening state are also given in the diagram of Figure 10.

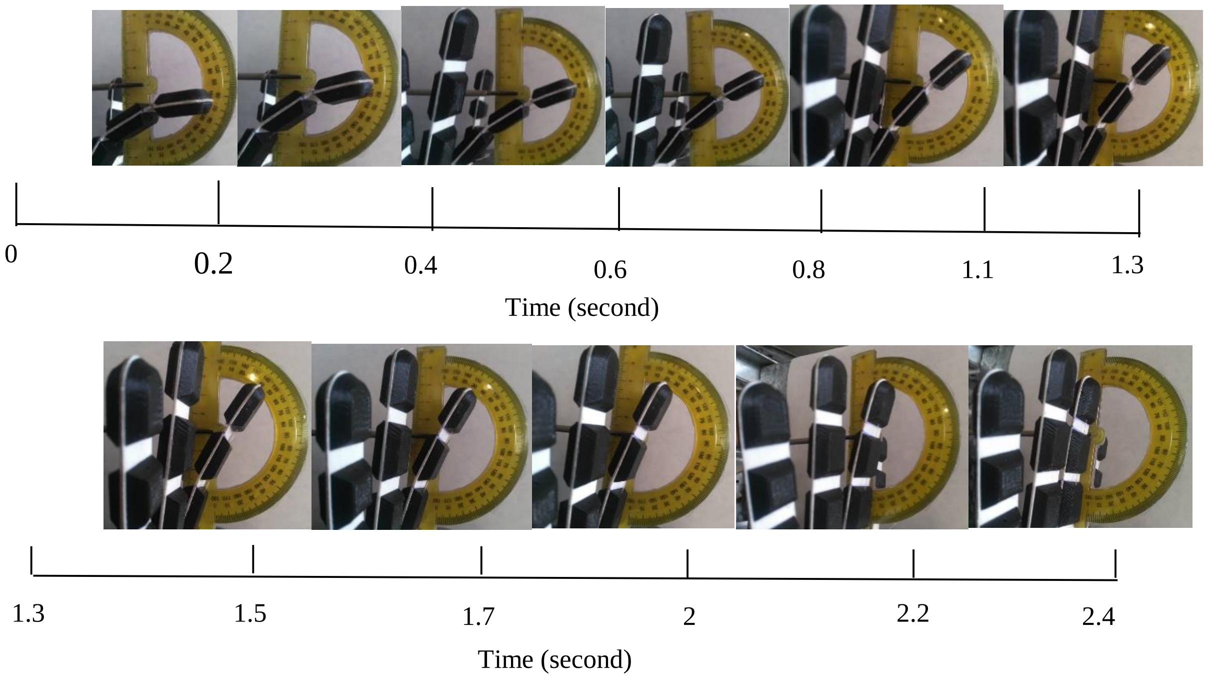


Figure 8. Opening state of the Flexi hand's finger

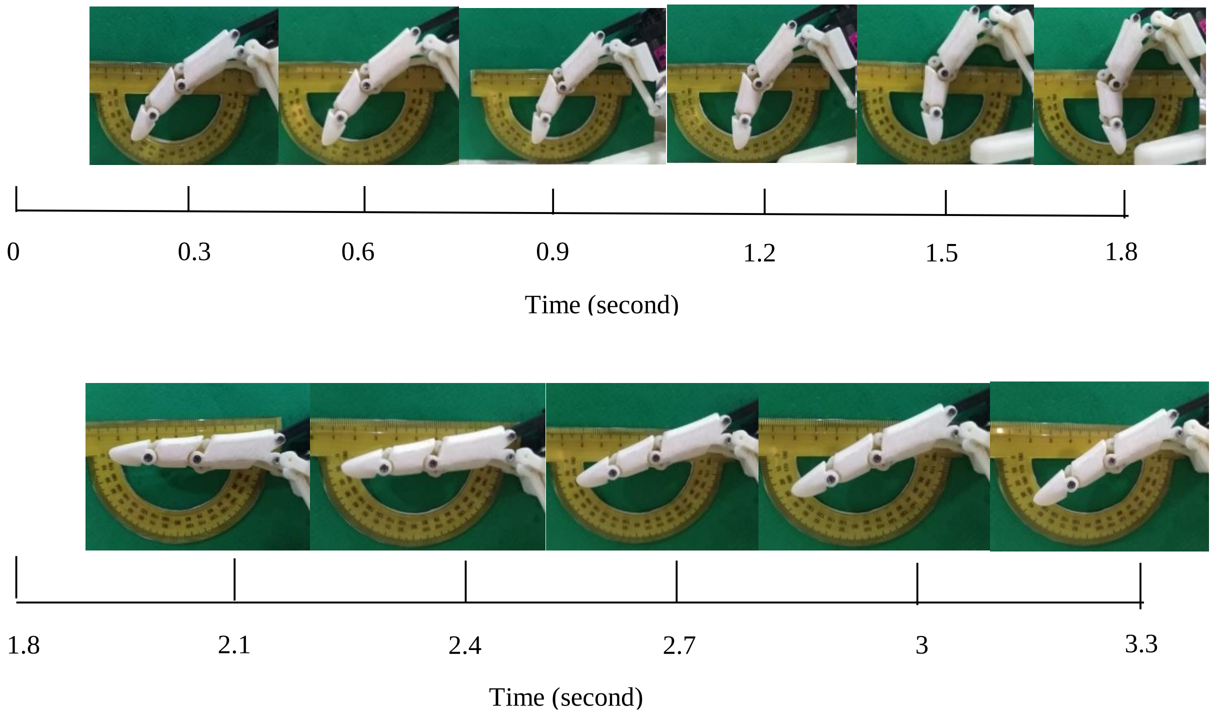


Figure 9. Opening state of the articulated hand's finger

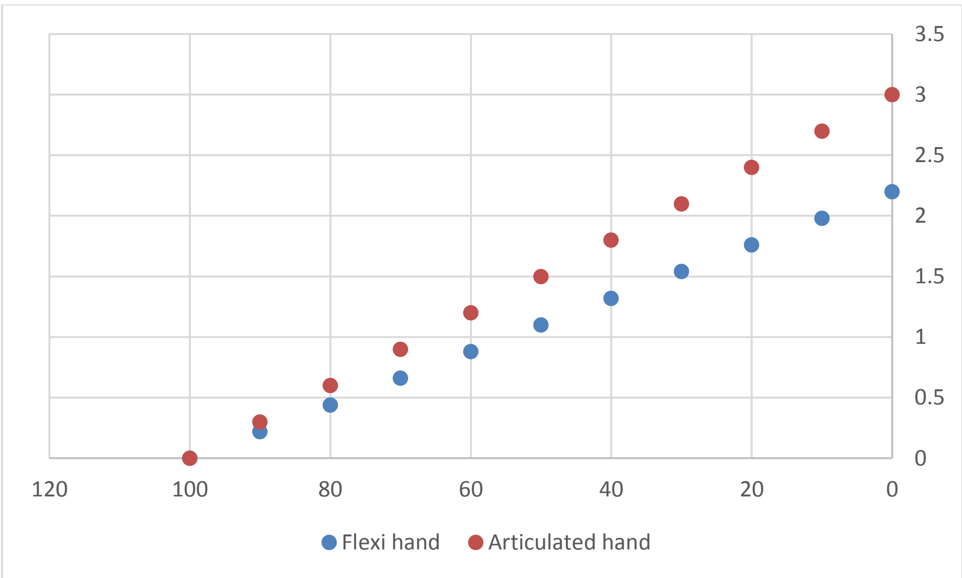


Figure 10. Comparison of the fingers of both hands in the opening position

4. Result and discussion

As it is clear from Figures 7 and 10, the finger of the flexi hand is closed faster, and the articulated hand's finger is closed with more delay. Furthermore, the finger of the flexi hand can easily bend up to 150 degrees, replicating the human hand's movement more similarly. Still, the articulated hand can bend up to 100 degrees at most. However, the knuckles of the articulated hand are closed simultaneously due to the rigid leverage, but in the flexi hand, this synchronization does not happen precisely.

In addition, in the opening state, the fingers of the flexi hand open faster, and the articulated hand opens with a longer delay. Moreover, the flexi hand's opening time is less than its closing time. The reason is that the soft TPU joint helps the fingers to return to the opening position faster. In addition, due to the use of a rigid joint in an articulated finger, the opening time of this finger is precisely the same as the folding time.

5. Conclusion

In this article, two flexi and articulated hands were manufactured using a 3D printer and ABS and TPU materials. The number of fingers and knuckles in both hands is similar to the human hand. In an articulated hand, the movement of the thumb is a bit different from the rest of the fingers so that this finger can close like the rest and rotate completely. As a result, it provides the possibility to make a proper adjustment according to the object's dimensions so that it can take the object completely without damage and the object is not released. According to the experiments in this article, the flexi fingers replicated the human hand's movement more quickly due to the use of TPU material in the joints, and they were easily bent up to 150 degrees. Still, the articulated fingers did so with a half-second delay. They could finally bend up to 100 degrees, demonstrating the flexi hand's superiority in replicating the human hand's movement more thoroughly and accurately.

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