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Designing and implementing a 3D printer using a microcontroller and evaluating its performance on ABS and PLA materials

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Abstract

Three-dimensional (3D) printing is one of the rapid modeling methods which has revolutionized the prototyping industry. 3D printers change thin layers of materials into 3D objects. These printers use a variety of techniques and materials. Still, all of them are capable of converting digital files containing 3D digital data, that is generated by 3D modeling software, into physical objects. These printers are used for various purposes. In this research, a new 3D printer using a micro controller is designed and implemented. To evaluate the performance of the printer on acrylonitrile butadiene styrene (ABS) material and polylactic acid, samples of specific sizes were produced. Then size of the produced samples was measured and the effect of temperature and speed changes on their length, width, thickness, and quality of surface were investigated. Finally, diagrams of size and quality variation towards temperature and speed changes determined the ideal temperature and speed for the two mentioned materials.

Keywords: 3D printing, Microcontroller, PLA, ABS, Production

1. Introduction

Rapid prototyping technology provides the ability to make prototypes for different models with different genders. This type of modeling creates and delivers the part model in less than a few hours. The rapid prototyping system of molten sediment and the next-generation printer are commercial rapid prototyping devices (Oluwajobi and Kolawole, 2021; Cadiou, 2021). This type of modeling creates and delivers the part model in less than a few hours. The rapid prototyping system of molten sediment and the

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subsequent printer are commercial rapid prototyping devices (Montes et al., 2021; Sivapalanirajan et al., 2020; Kumar et al., 2022).

Among the many effective parameters available, the layering direction parameter and fiber angle are the most important in the process of fused deposition and subsequent printing. The tests performed are to measure the effect of layering direction on the mechanical properties of anisotropic materials of parts made by fused deposition method and 3D printer. Based on the experiment, the compressive strength of the fused sediment sample with an axial layering direction is equal to 26.41 MPa, which is 11.6% greater than the strength of the fused sediment sample with a transverse layering direction, also in the 3D printer, the sample with the diagonal lamination direction has the highest strength, which is 16.9 MPa (Wittbrodt et al., 2013).

The effect of adding aluminum oxide nanoparticles with different weight percentages on the mechanical properties of acrylonitrile butadiene styrene aluminum oxide nanocomposites on the mechanical properties of injection molded parts prepared from acrylonitrile butadiene styrene aluminum oxide nanocomposites was experimentally tested and analyzed. A new approach to improve the performance and versatility of layer construction, which is an emerging technology, is presented (Dahle et al., 2013). This technology enables the creation of physical prototypes of 3D parts directly from computer models using a 3D printer connected to a personal computer. Existing layered manufacturing processes work by considering computer models as a single integrated unit. A new 3D printing method, especially rapid prototyping based on acrylic photopolymer material, making design molds (polydimethylsiloxane), making microfluidics based on rapid prototyping (RPT), and making research tool platforms based on RPT have been used. In order to estimate the surface roughness of the parts printed with the technology of melting and layering of polymer or metal materials, a 3D model is prepared from it by a 3D scanner, and the size of the roughness is obtained and treated with the help of chemicals that are solvents of polymer materials (Galantucci et al., 2009).

In this research, the melting and layering technology of fused deposition modeling has been used for the laboratory construction of a sample of rapid prototyping devices. This method is one of the many rapid prototyping methods, has advantages over other methods, which has been able to open its place in engineering design offices and homes. The rapid prototyping method with the melting and layering technology of polymer or metal materials, in addition to being light and portable, is very low-cost and has a much simpler operation and consumes relatively less energy than similar samples. In this paper, it has been tried to significantly reduce the design and construction cost by using simpler materials and equipment.

2. Method

The mechanical hardware system that is used in this article on this rapid prototyping, the same hardware as common CNC machines, is used from a three-axis movable table. The system presented is a small laboratory sample. Therefore, its moving dimensions are considered to be a cube of 20 cubic centimeters. The axes of the mentioned device are designed for these dimensions. In order to reduce errors and mistakes during the construction phase, a 3D design software should be used for the initial design of this device. Catia 3D design software is used for design. Before becoming a 3D printer, the current hardware system used to be a two-degree-of-freedom Figure 1. The motors used in this system are of DC type. To increase the accuracy of the system, a stepper motor with a step of 1.8 degrees has been used. Stepper motors (Figure 2) are connected to the screw heads using couplings.

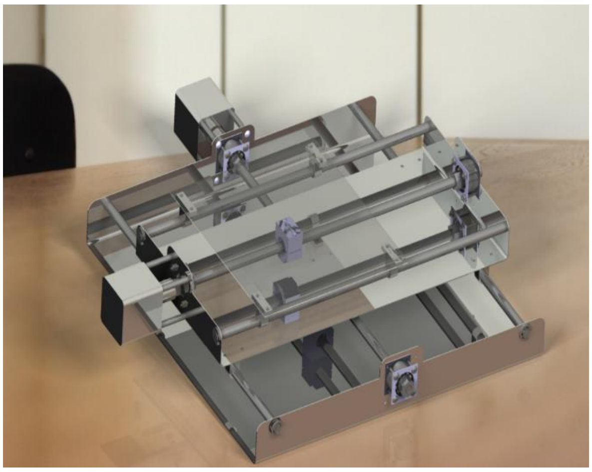

Figure 1: 3D prototype of two degrees of freedom table

Figure 2: stepper motor

To improve the quality of movement and increase the speed of the printer, its movement transmission system has been changed from bolts and nuts to belts and pulleys. (Figure 3) Both the speed of the system has increased, its accuracy has increased, and its fluidity has improved. Now, in order for this two-level table to become a printer system, it must be upgraded to three levels. This will happen by adding the Z axis to it. The Z axis (Figure 4) should move an extruder linearly in the vertical direction. This axis cannot be moved well with a pulley and a belt. From the bolt and nut, not in the previous form, but from a completely accurate steel screw and a non-homogeneous nut with a screw and a little softer than the screw material so that its movement becomes smoother and smoother. (Figure 5).

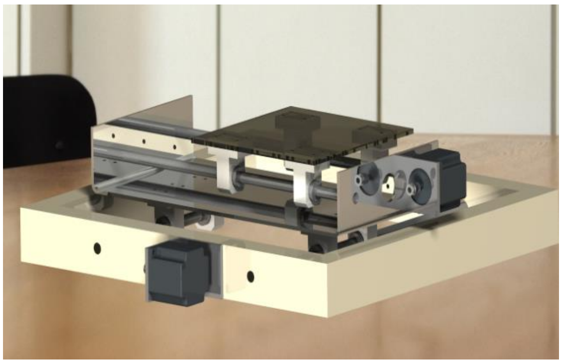

Figure 3: x and y axis of the new system

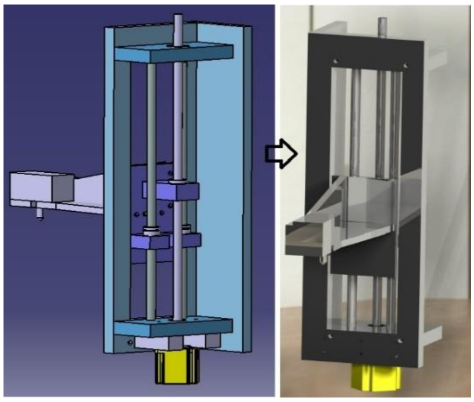

Figure 4: System axis

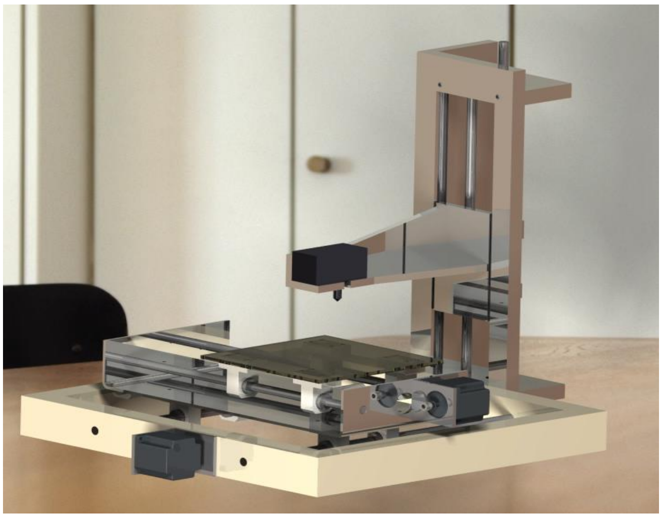

Figure 5: 3D image of the designed system

The first step in the program designed for the current system is to position the axes of the machine at the zero point, which is controlled by the built-in reed relays, then the motors are commanded to move and stop after reaching the relays. This point is also the zero point of the nozzle. The temperature of the hot plate and heater of the extruder is read using temperature sensors, and if the temperature does not reach the set limit, no action is taken. After the temperature reaches the set limit, the machine's axis motors are ordered to move and the starting point of the work is given to the distance of each of them compared to the reed relays. After placing the nozzle at the starting point, at the same time as the work starts, the extruder motor pushes the consumable towards the nozzle, and the external injection is performed, and the given design proceeds according to the plan, and after the injection is finished, the Z axis is cut off. Pull the extruder up and again the motors drive the nozzle to the zero point.

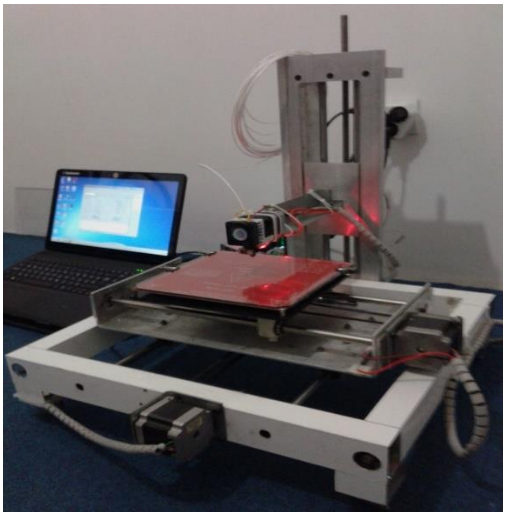

Figure 6: Image of the implemented system

3. Results

3.1. Factors affecting the quality and dimensions of parts

Accuracy of mechanical hardware: the higher the accuracy of mechanical hardware, the higher the accuracy of parts, such as the type of parts used in the transmission of the movement of engines, the parts on which movement is performed, such as the balling bush and rod, the one-piece chassis used in the pulley machine The adjustment of the belts, the sensors used to control the movement of the axes, the alignment of the device plays a significant role in controlling the vibration of the nozzle. Electronic hardware and motor drivers: There are many drivers in the market for starting stepper motors, which are different in price compared to their prices, and have a great effect on the movement of the motors and the smoothness of their operation, the smoother the motors and the less vibration. If the motor side is transferred to the extruder and melted materials, the quality of the produced parts will be more suitable. Heat Bed: it plays an important role in the cooling and uniform cooling of molten materials, and the gradual cooling of the production part makes the part not change shape after cooling.

Thermometers: measuring the temperature of the extruder with a high-quality thermometer is important because by obtaining the actual temperature of the nozzle heater, we can apply the necessary instructions in the micro and directly affect the quality of the molten material injection from the nozzle, the injection speed and control the heater temperature value.

Extruder motor speed: Extruder motor speed is as important as other things, which has a direct relationship with the heater temperature, and the higher the temperature, the motor speed should be reduced and within a temperature and speed range, it should reach a reasonable level in relation to the quality of the material injection.

In order to increase the surface quality of the printed parts by the technology of layering of melted materials, after printing, they are immersed in a bath of chemicals such as acetone, which are solvents for polymer materials, for the necessary time until the protrusions caused by the contact of the nozzle with the surface of the part or The steps created by the print material itself are dissolved in the chemical and polished.

3.2 The results obtained from the graphs extracted from the samples produced by the 3D printer

In order to obtain the most ideal test piece produced by the 3D printer, pieces with different temperatures were produced and their dimensions were measured with a relatively accurate measuring tool, and their results were presented in graphs.

3.2.1 Investigating the effect of temperature on ABS material dimensions

In this research, sampling was attempted at the lowest temperature at which ABS material can be melted. ABS material begins to melt at a temperature of nearly 200 degrees Celsius, but before it reaches the work surface, due to the low temperature, the material starts to cool down and is unable to print. At a temperature of 200 degrees Celsius, the material melts and reaches the hot plate, but it gets cold in the first rows and does not stick to the work plate and is not able to print at all. When its temperature increases by 5 degrees, the material sticks to the bottom of the work surface after several rows, but it does not completely stick to the print surface so that the printing process is complete, and the produced piece due to the material not sticking to the work surface has a wave and sticks to the tip of the nozzle and passes through the row. The next waves are removed and the produced sample is wavy. The next piece is produced for a temperature of 5 degrees higher than the previous one. This time, the material is more fluid than the subsequent layers in the injection chamber, which is at a constant temperature at the beginning of the injection, and it adheres well to the work, but because this temperature is in the row. The next layers lose their stability. After a few rows, the material loses its adhesion quality compared to the previous layers and the printing process is incomplete. This process is repeated until the temperature of 230 degrees Celsius and shows itself in different rows each time. For the ABS material at a temperature of 235 degrees Celsius, all the rows are placed together and gradually find their order, but due to the low temperature, the rows take on a wave shape and this problem makes the obtained dimensions of the samples to fluctuate These fluctuations in the rows, at different temperatures, due to the juxtaposition of the rows in different samples, the dimensions of the samples are different and do not have a particular stability in consecutive temperatures in a regular manner. The quality of the surface of the parts improves as the temperature rises, and according to the measurements extracted from the samples produced at a certain temperature (275 degrees Celsius), the dimensions of length and width are close together, and the thickness of the work is relatively to the desired size and relative to the diameter of the nozzle and The distance between the nozzle and the work surface is proportional and an ideal sample is produced. As the temperature increases, the ratio of speed and temperature is separated, and due to the high temperature of the injected substance, the amount of injected substance is increased compared to the previous samples, and this time because the output of the excretory substance is more and its pasty form is fluid. It moves and cannot be controlled. Due to the high flow rate, the exogenous material hits the work area and returns to the nozzle, and due to the collision of the nozzle with the previous rows, it causes their shape to change and distorts the work surface, and the produced sample is disturbed both in terms of dimensions and the quality of the surface. It is porous. At a temperature higher than 280 degrees Celsius, ABS material loses its properties and changes color due to high temperature and reaches boiling point. (Figure 1-5) The sampling temperature range for ABS is 205-306. The ideal sample for ABS is obtained at a temperature of 275 degrees Celsius. It should be noted that ABS requires less cooling time than PLA and loses its temperature sooner. The samples produced for ABS are at a working surface temperature of 100 degrees Celsius.

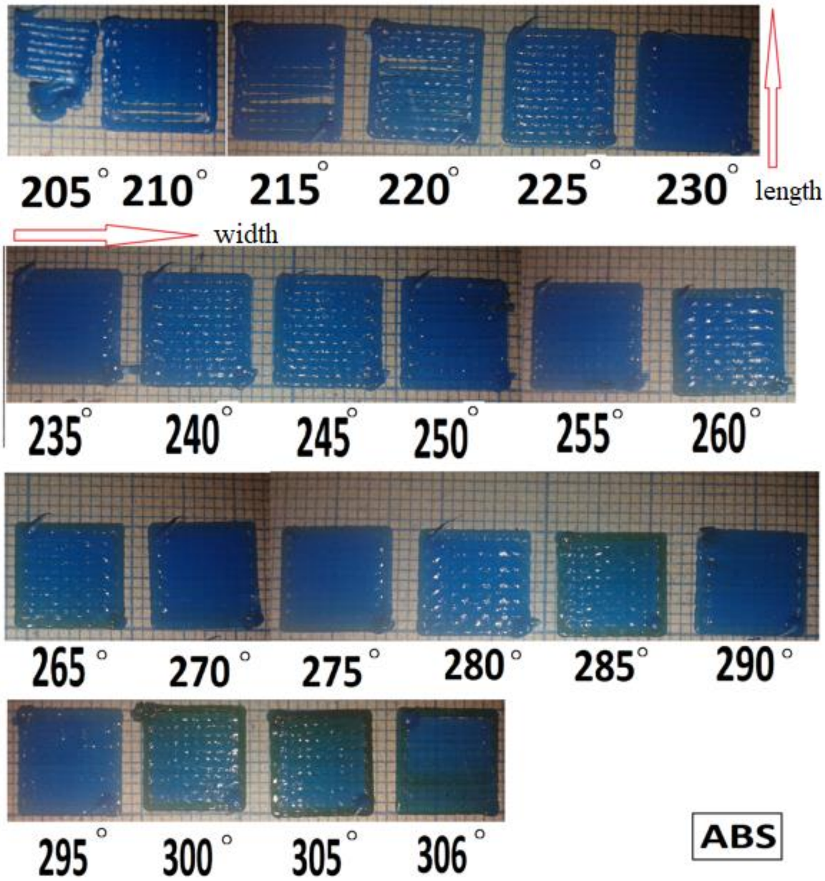

Figure 7: Samples produced at 205-300 degrees Celsius

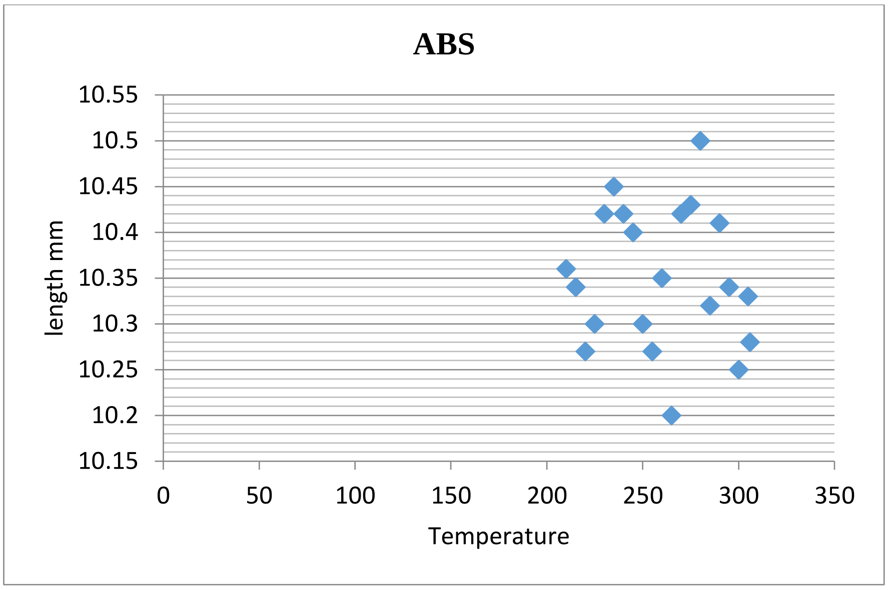

Figure 8: Effect of temperature on ABS length

In the diagram (8) which shows the changes in the length of the ABS sample and the diagram (9) shows the changes in the width of the ABS sample with the change in temperature, at low temperatures due to the wave shape of the injectable material and the effect of this issue on the juxtaposition of the rows and Their effect on each other and as a result their effect on the size of the sample and at high temperatures due to excessive temperature and high fluidity of the material and its adhesion to the edge of the nozzle and its collision with the previous rows and its effect on the sample size of this deformation in the form of injection material both at high temperatures and at low temperatures in different rows is not the same and as a result it does not have the same effect in different samples and causes the dimensions to increase and decrease according to The equation obtained from the graph does not have a positive correlation coefficient until the temperature reaches its optimal level, and according to the graph (9) which shows two graphs of length and width placed side by side, the length and width at a temperature of 275 degrees Celsius has approached and according to the graph (10) which shows the changes in thickness with increasing temperature, it has approached the desired size.

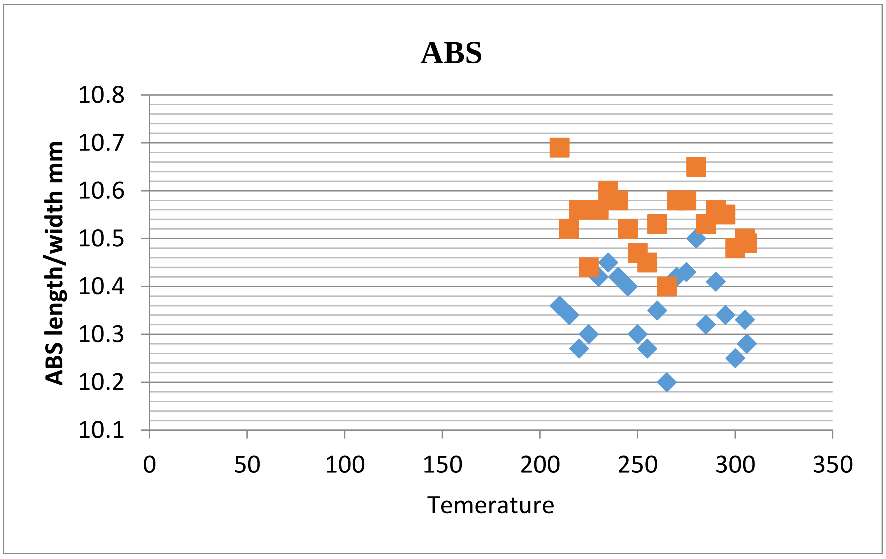

Figure 10: ABS length and width comparison

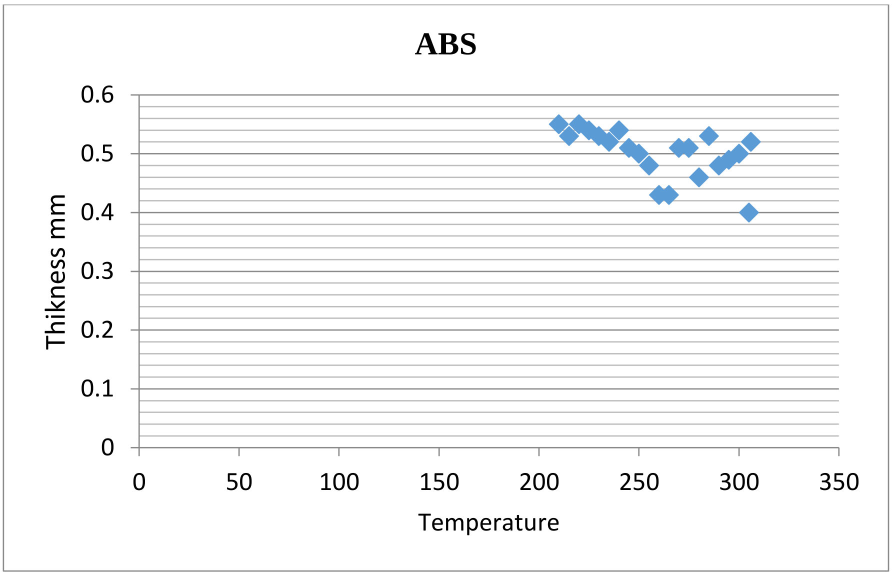

Figure 11: Effect of temperature on ABS thickness

In diagram (11), it can be seen that the effect of temperature changes on the thickness of the material. There is a relatively positive correlation coefficient compared to other dimensions of the sample. This issue can be due to the fact that the sample is single-layer, and if we add the next layers to it, it will show itself better.

5.2.1. Investigating the effect of temperature on PLA dimensions

For PLA material, sampling has been done at the lowest temperature at which the material can be melted. PLA material reaches the melting temperature at a temperature of nearly 200 degrees Celsius. According to the sampling done, the effect of temperature has been investigated at different times. The extruding action in the initial rows is because the material of the initial rows has reached a stable temperature in the injection chamber and has taken on a completely sticky state, they stick to the work surface, but because after a few rows the temperature of the extruding material comes lower, it has not acquired the adhesive properties and does not stick to the work surface, and the printing process is not performed until the injection and adhesion mode takes place as the temperature rises, and the printing process is performed. The rows remain empty and the produced sample has holes in it. By increasing the temperature, these holes become smaller compared to the added temperature and disappear completely at 225 degrees. Because the excretory substance has a wave form at low temperatures. In PLA material, just like ABS, due to the placement of wavy rows next to each other and the effect on each other at different temperatures, this defect affects the dimensions of the samples with different sizes, and for this reason, the dimensions of the samples fluctuate. It does not have a special order until at a certain temperature (240 degrees Celsius) the dimensions of the width and length of the sample approach each other (Figure 12) and the ideal sample shows itself. By raising the temperature of the injected material, because the material has taken on a more fluid state and the extruding material has a high speed, and the material exiting the nozzle due to hitting the edge of the nozzle and remaining on its edge has hit the previous layers and It causes them to be confused. It has a negative effect on both the dimensions and the quality of the work. This action becomes more visible as the temperature rises. At a temperature higher than 265 degrees Celsius, PLA material loses its properties and changes color due to high temperature and reaches the boiling point. The sampling temperature range for PLA material is 200-265 degrees Celsius and the ideal temperature for PLA is 240 degrees Celsius. The temperature of the PLA work surface is 70 degrees in this sampling. The cooling time of PLA is longer than that of ABS, and it loses its temperature later, and a fan is needed to cool it down quickly. As can be seen in (figure 13), the fluctuations in the dimensions of the PLA sample at high temperatures due to excessive fluidity and at low temperatures due to the lack of adhesive properties and having a wavy shape and non-continuity of the exuding material and There is no positive correlation coefficient for the non-paste form of the material and in both cases the material hitting the edges of the nozzle and finding the waveform of the working surface. The graphs of the effect of temperature changes on the dimensions of PLA are similar to ABS.

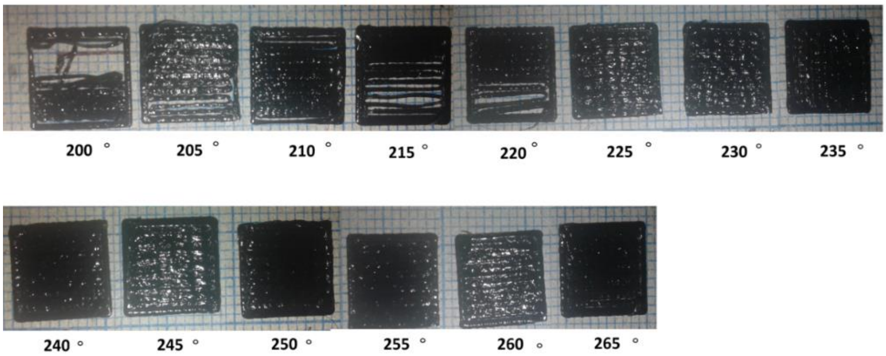

Figure 12: Samples produced at 200-260°C for PLA

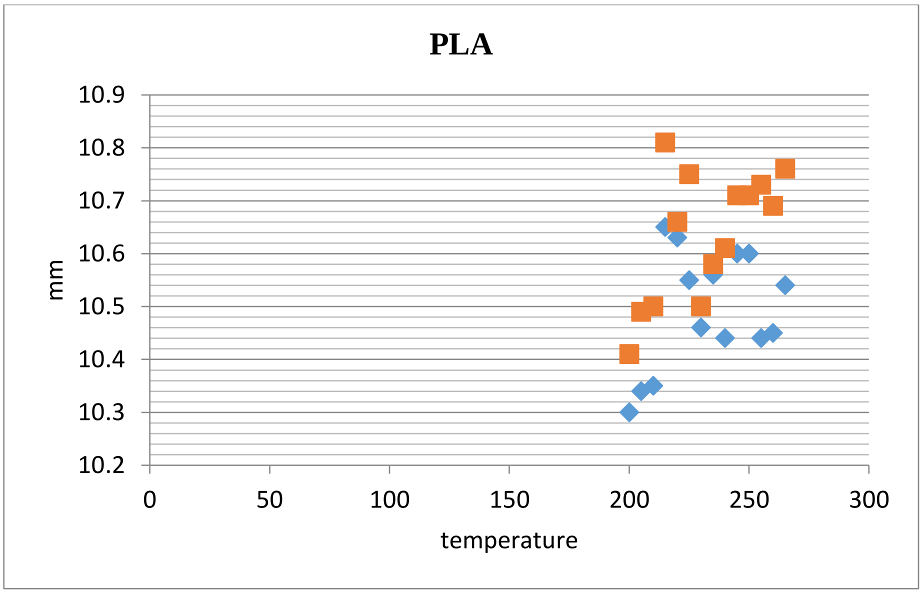

Figure 13: Comparison of length and width of PLA with temperature changes

By considering (Figure 14), we come to the conclusion that temperature changes have a significant effect on the thickness of the material because the surface of the material is in direct contact with the nozzle more than other dimensions, and temperature changes both at high and low temperatures affect the quality. The projection of the substance and the size of the diameter of the substance are effective. Although the correlation coefficient of this graph is more positive than the graphs of other dimensions, we should not ignore the fact that the thickness of the sample has been examined only in one layer, and for a better investigation, sampling should be done from several layers like other dimensions of the sample and check its dimensions.

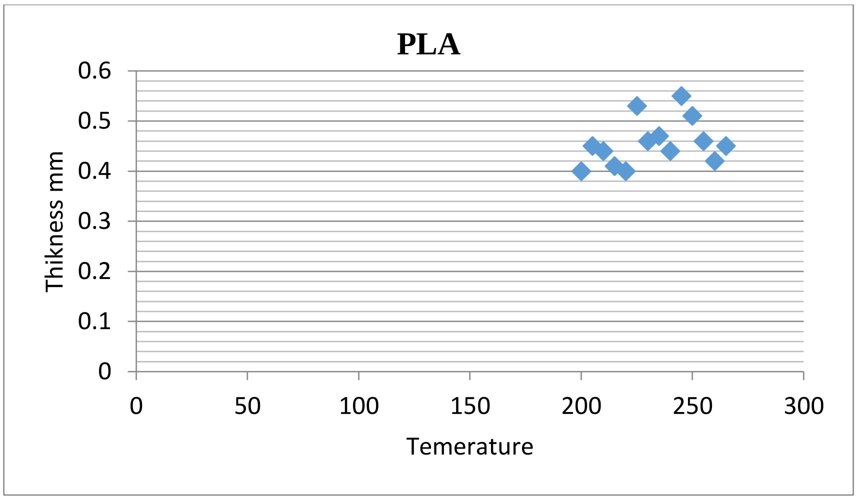

Figure 14: Effect of temperature on PLA thickness

5.2.1. Investigating the effect of extruder speed on dimensions and surface quality of ABS and PLA materials

By checking the graphs extracted from the dimensions of the samples produced at different temperatures and reaching the specific temperature of the ideal sample, the desired sample is selected to check the changes in the speed of the extruder on the dimensions and surface quality of the produced part. The speed of the extruder motor used in the current system is divided into seven speeds with equal intervals. The selected sample was produced with the maximum speed of the extruder. By reducing the speed of the extruder, the material comes out of the nozzle at a slower speed, which increases the diameter of the material coming out of the nozzle, when the layers are placed together, they press each other and the material is pushed upwards from the work surface, and hits the edge of the nozzle. And the thickness of the produced sample increases. As a result of increasing the thickness of the sample and its impact on the edge of the nozzle, the quality of the surface of the piece decreases due to the impact with the nozzle, and the quality of the produced sample deteriorates as the speed of the extruder decreases. To the extent that the produced sample has lost its true shape and cannot be measured.

In the graphs of the effect of extruder speed on the dimensions of the material, it can be seen that as the extruder speed decreases, the dimensions of the sample increase due to the reasons mentioned in the previous section. The correlation coefficient seen in the graphs is positive. As the dimensions increase, the quality of the sample decreases. These results are almost similar in all charts of PLA and ABS materials. In Figure (15), the effect of speed on the quality of the samples can also be seen with the naked eye.

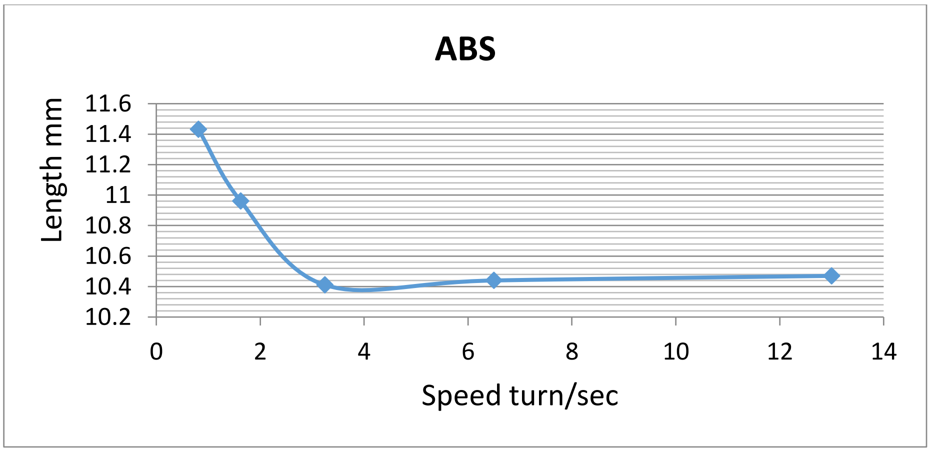

Figure 15: Extruder speed on ABS length

According to the figures (16-18), at very low speeds, the width of the sample increased much more, and in the last two speeds, it reached its stability and real size. This procedure is similar in the graphs of the effect of speed on the length and thickness of ABS material. And we conclude that the effect of speed on all dimensions of matter is the same.

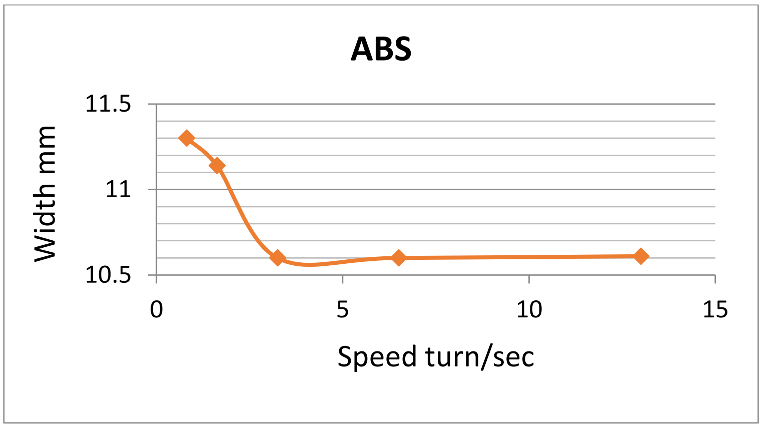

Figure 16: Extruder speed on ABS width

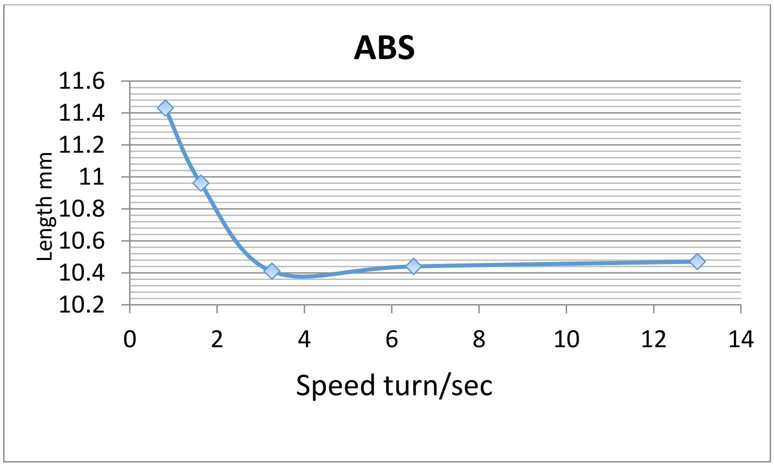

Figure 17: Comparison of length and width with changes in extruder speed

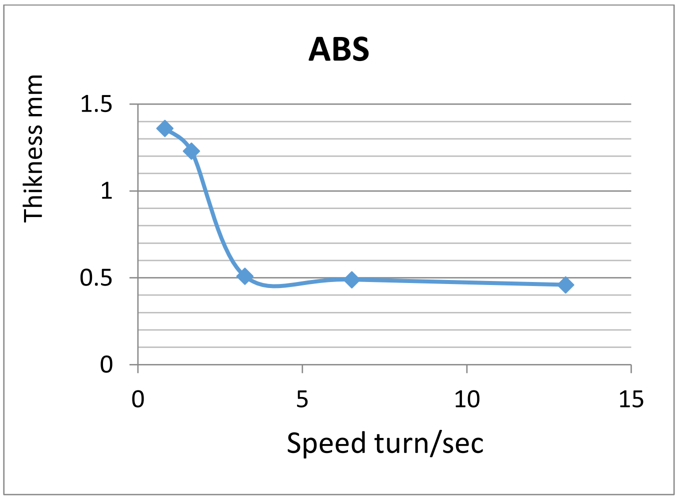

Figure 18: Extruder speed on ABS thickness

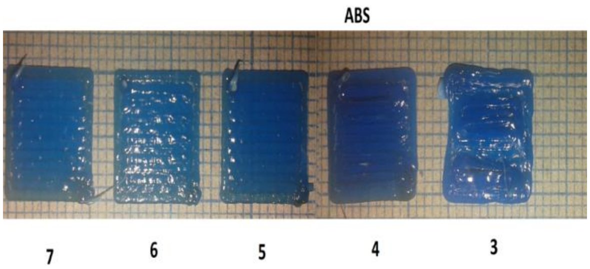

Figure 19: Samples produced at the ideal temperature of a sample at different extruder speeds for ABS

By examining the graphs of the effect of extruder speed on the dimensions of PLA material, we can see that the correlation coefficient of this material is lower than that of ABS. This problem happens due to the creation of holes in the middle rows (Figure 19), which are visible in middle speeds. These holes have made the inside of the material to be hollowed out, which has a great impact on the final accuracy of the parts. As a result, the dimensions of the samples of this material fluctuated a lot and led to a decrease in the correlation coefficient of the graphs of this material compared to the ABS material.

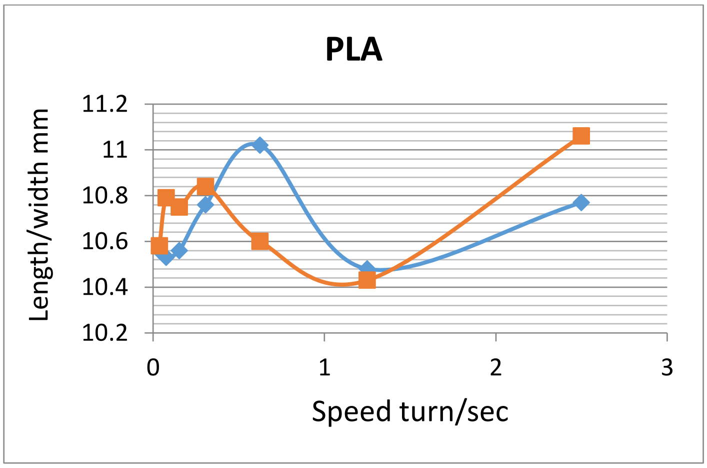

Figure 20: Comparison of length and width with changes in PLA extruder speed

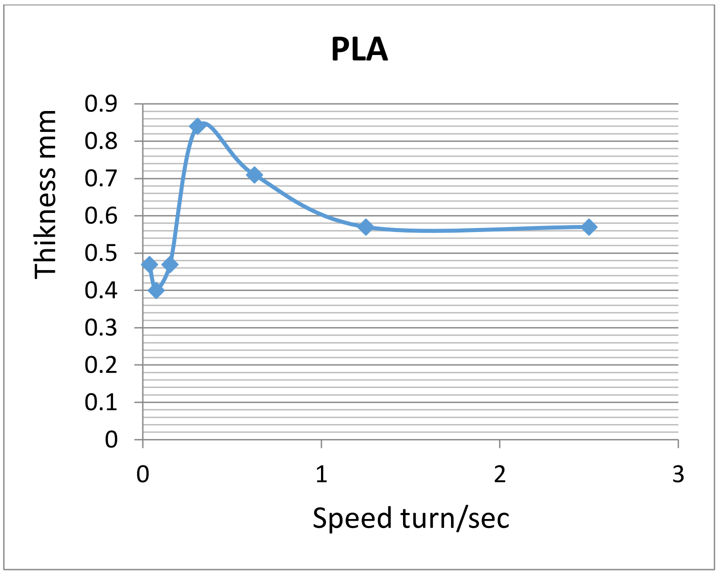

Figure 21: Effect of extruder speed on PLA thickness

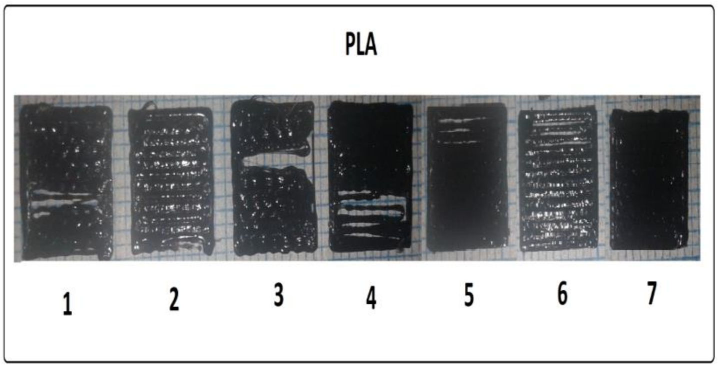

Figure 22: Samples produced at the ideal temperature of a sample at different extruder speeds for PLA

4. Conclusion

After the construction and implementation of the current system, samples have been produced to reach the ideal sample in a temperature range with the same distance. This period has been completed from the lowest temperature at which the material starts to melt to the temperature at which the material loses its quality and reaches the boiling point. The temperature range of ABS material is (200-306) degrees Celsius and PLA material is (265-200) degrees Celsius. The temperature of the material is increased from the lowest temperature to the highest temperature with a temperature interval of 5 degrees. The dimensions of the produced samples were measured with a measuring tool with an accuracy of 0.01 mm. In order to get the ideal size, charts have been extracted from the obtained sizes. By putting these graphs together, we noticed a topic that shows that at a certain temperature, the dimensions of the sample are close to each other, and the quality is better than other samples, which is 275 degrees Celsius for ABS and For PLA, it is 240 degrees Celsius. In the graphs obtained, there is no acceptable correlation coefficient due to the fluctuations in the material ejected from the nozzle at low and high temperatures. The graph of the effect of temperature on the thickness of the produced parts shows a more acceptable correlation coefficient compared to other dimensions of the samples, which is due to the fact that the produced sample is one layer and will show itself well in the next layers and the correlation coefficient will reduce After reaching the ideal sample at a certain temperature, this sample was selected for changes in the speed of the extruder, and this time the changes in the speed of the extruder were applied. If the extruder is reduced, the thickness will increase and the quality of the parts will decrease. The best mode of this test is at the highest speed of the extruder used in this system.

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