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Screw Modification on Plastic Extruder Machine

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Abstract

Plastic extruder machine is a machine that processes material changes from the form of plastic making into extruded changes from solid to liquid form. In the plastic extruder machine there are many machine components used. The components found in the plastic extruder machine are the frame, reduction gear, puller roller, bearing, v-belt, electric motor, pulley, stepper, clutch, air chamber, nozzle, feeder, compression spring, panel box and screw. This study aims to optimize the performance of the plastic extruder machine, which is a machine that functions to process material phase changes from solid plastic freezing to liquid melt through an extrusion mechanism. This study uses an experimental method by changing the screw diameter which was originally 37 mm to 41 mm in addition to changing the diameter size, changes were also made to the screw pitch size which was originally 12 mm to 14 mm. The modified screw that was tested using PLA material with a rotation of 38 rpm produced a flow rate of 0.00129 m ^ 3 / s with a maximum pressure of 10.2866 Mpa. While the screw before modification produced a flow rate of 0.000921 m^ 3 / s and a maximum pressure of 9.5151 Mpa. From the data obtained from the screw, the modification results obtained quite good results compared to the screw before modification.
Keywords**:** *screw modification; plastic extruder machine; pla (polylactic acid); single screw extruder*

1. Introduction

A plastic extruder machine is a machine that processes the change of material from the shape of plastic ore to extruded (change from solid to liquid form) [1]. In plastic extruder machines, there are many machine components used. The components contained in the plastic extruder machine are the frame, gear reducers, pulling rollers, bearings, v-belts, electric motors, pulleys, steppers, couplings, water containers, nozzles, feeds, compress springs, panel boxes and screws. This study aims to optimize the performance of the plastic extruder machine, which is a machine that functions to process material phase changes from solid plastic freezing to liquid melt through an extrusion mechanism. However, in the milling process, the main component is screws. Screws are the main components of a plastic extrusion machine that function as a driving shaft, and a cutter, as well as a hot plastic mixer [2].

Based on existing tools, there are shortcomings, namely in the screw part. The existing tool when operating the plastic ore machine that enters the screw is slow to come out of the nozzle, this is caused by the plastic ore passing through the screw accumulating on the back of the screw tip. Therefore, it is necessary to redesign the screw so that the plastic ore that comes out becomes more efficient. To ensure process continuity, it is recommended that the ratio between the screw diameter and the barrel diameter be between 0.005 – 0.002 in (0.05 mm) [2]. The size of the screw diameter affects the flow of plastic in the barrel while the "Goover" in the journal [2] states that the diameter of the barrel usually ranges from 1 – 6 inches. The recommended helix angle is 17.65° for maximum forward thrust [3] . The thread geometry can affect the flow of the plastic in a plastic extruder machine consisting of pitch, depth and flight. Large pitches allow for more plastic volumes to flow per screw rotation while small pitches increase internal pressure and help speed up

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the process of melting and homogenizing materials [24]. Large depths provide more space for material to run in the screw while smaller depths for the liquefaction and metering pathways, to increase pressure, accelerate defrost and improve outflow [25]. High flight (wing thread) and flight thickness affect the shear rate and mixing efficiency and special flight designs (such as barrier flight or maddock mixers) increase temperature homogeneity and viscosity, helping to blend and dilute materials more perfectly [26]. In the process of extrusion, it is not easy to get the shape of the product with the right tolerance dimensions, several factors may affect it. These factors include: rotational speed, amount of pressure, temperature and type of plastic material (viscosity and melting point) used and screw design [2,27].

The planning design that will be done on the screw is to add variety to the screw with the aim of increasing the output of the outflow. Simulation and flow calculation to support the redesign of plastic extruder threads using computational fluid dynamics (CFD). Because in the previous screw design, the distance between the barrel and the screw was too loose, it caused a lack of pressure that entered during the process of pushing the plastic ore towards the nozzle. So it is necessary to redesign by changing the thickness of the screw and the depth of the canal, so that the machine works more optimally.

2. Method

This study employs an experimental method by directly modifying the diameter and pitch sizes with the aim of obtaining better flow, pressure, and filament quality compared to the previous screw design. Below is the research flowchart, as shown in Figure 1.

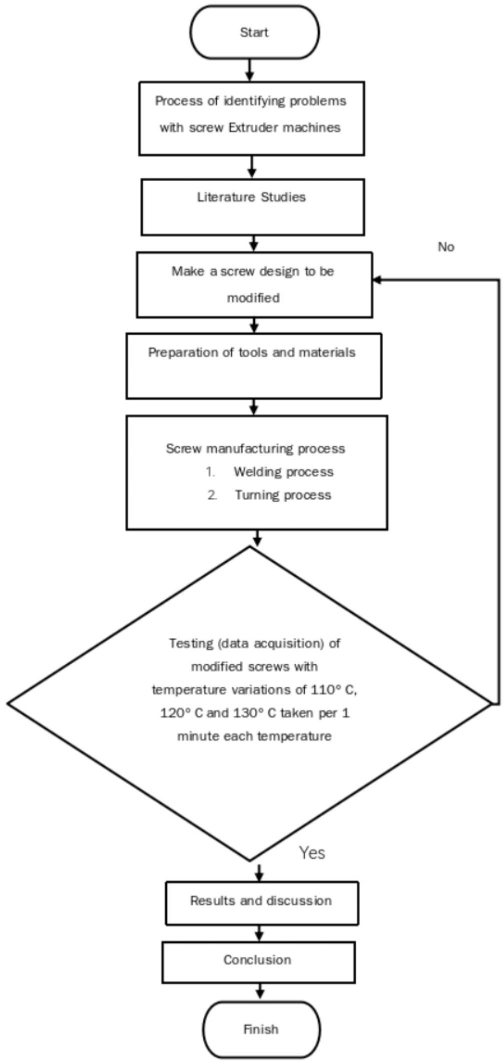

Figure 1. Research flow chart

2.1 Comparison of the previous and new screw designs

a. Screw design before modification

Below is the image of the screw design prior to modification:

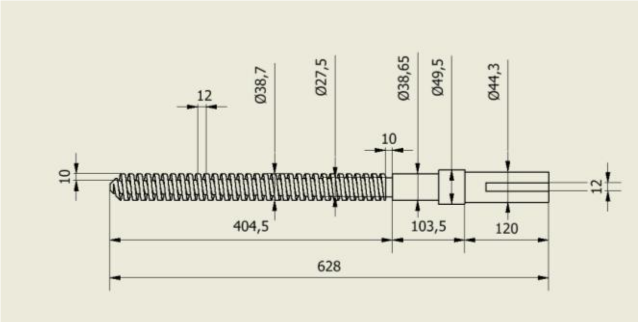

Figure 2. Previous Screw Design

Figure 3 shows that the gap between the barrel and the screw is quite loose, causing the pressure generated by the screw to be less than optimal because the transportation mechanism in a single-screw extruder relies on the friction generated between the material and the barrel.

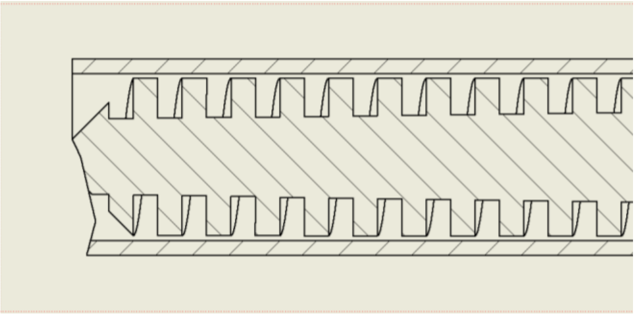

Figure 3. Comparison of Screw Diameter with Barrel

b. Screw Design After Modification
Below is the image of the screw design after modification:

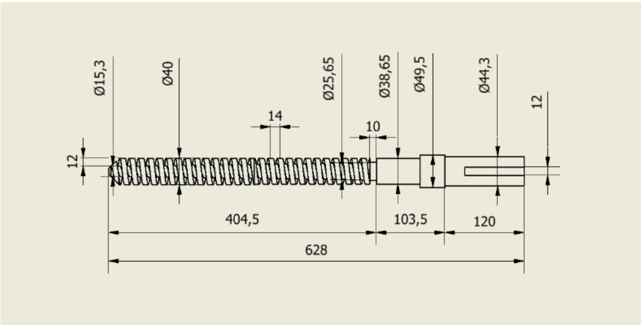

Figure 4. Modified Screw Design

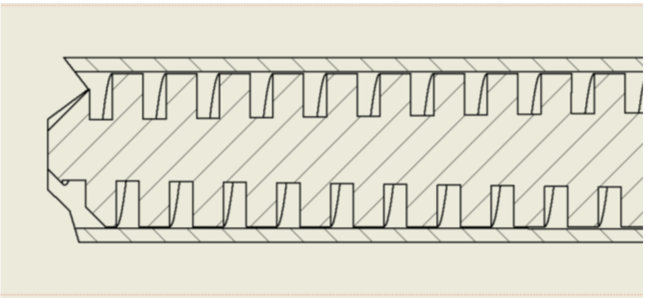

Figure 5. Comparison of Screw Diameter with Barrel

Figure 5 (the comparison of the screw diameter with the barrel) shows that the design between the barrel diameter and the screw diameter has become tighter. This adjustment is intended to maximize the pressure generated by the screw; not only was the diameter changed, but the pitch and channel depth were also modified to further optimize the performance of the modified screw.

3. Results and Discussion

3.1 Machining Calculations

a. Welding Machine
- Calculation of Welding Material V
olume

To determine the volume required for the welding process, the following formula is used:

$$m = \frac{(\rho \cdot v)}{DE}$$

Where:
m = amount of welding wire required
ρ = density of steel
v = volume to be welded
DE = deposition efficiency

Calculation:

$$m = \frac{\rho \cdot v}{DE}$$

$$m = \frac{(7{,}8 \text{ gr/cm}^3 \cdot 184{,}89 \text{ cm}^3)}{0{,}62} = \frac{1442{,}142 \text{ gr}}{0{,}62}$$

$$= \frac{1{,}442 \text{ kg}}{0{,}62} = 2{,}326 \text{ kg}$$

Thus, the required welding wire is approximately 2.326 kg.

b. Lathe Machine
- Calculation of Cutting Speed

Cutting speed (Cs) is the speed at which the cutting tool moves relative to the workpiece. It is usually provided by the tool or workpiece material specifications. The formula used is:

$$Cs = (D \times N) \div 1000$$

- Turning of the Screw

Material = ST 37
Workpiece diameter = 42 mm
Length = 220 mm
Cutting tool = HSS
Amount to be turned (material removal) = 2 mm

$$Cs = \frac{\pi \cdot D \cdot N}{1000}$$

Where:
Cs = cutting speed (m/min)
D = workpiece diameter (mm)
N = spindle speed (rpm)

Perhitungan:

$$N = \frac{Cs \cdot 1000}{\pi \cdot D}$$

$$= \frac{75 \cdot 1000}{3{,}14 \cdot 42} = 568 \text{ rpm}$$

The machine is set to 500 rpm (choosing the nearest practical value based on the lathe's settings).

- Calculation of Feed Rate

The feed rate (F) is given by:

$$F = f \cdot n$$

Where:

f = feed per revolution (mm/rev)

n = spindle speed (rpm)

Calculation:

Given:

f = 0.2 mm/rev

n = 500 rpm

F = 0.2 × 500 = 100 mm/min

- Average Turning Time

Using the formula:

$$tm = \frac{\text{Total turning length (L)mm}}{\text{Feed rate (F)mm/menit}} \text{minutes}$$

Where:

L = la+ l (mm)

F = f.n (mm/menit)

Information:

f = nutrition in rotation (mm/put)

n = workpiece rotation (rpm)

l = flat turning length (mm)

La = Sculpt Star Distance (mm)

L = total length of flat turning (mm)

F = feeding speed mm/min

Workpiece diameter D = 42 mm turned down to d = 40 mm over a length l = 220 mm, with la = 0 mm (starting distance)

- Thus, L = 220 mm
- F = 0.2 × 500 = 100 mm/min

tm = 220 ÷ 100 = 2.2 minutes

c. Screw Extruder Calculations

- Volumetric Flow Rate

The volumetric flow rate is calculated using:

$$Qd = 0{,}5\pi^2 D^2 N d_c \sin A \cos A$$

Where:

Qd = Discharge flow volume (m3/s)

D = Outer diameter Screw (m)

N = Rotation per minute (Rpm), (Put/s)

dc = In canal (m), (mm)

sinAcos= Tilt angle (°)

- Calculation of screws after modification:

$$Qd = 0{,}5 \cdot \pi^2 \cdot 0{,}04^2 \cdot 38 \cdot 0{,}012 \cdot 0{,}39 \cdot 0{,}92 = 0{,}00129\ m^3/s$$

- Calculation of screws before modification:

$$Qd = 0{,}5 \cdot \pi^2 \cdot 0{,}037^2 \cdot 38 \cdot 0{,}01 \cdot 0{,}39 \cdot 0{,}92 = 0{,}000921\ m^3/s$$

- Maximum Pressure

The following is the formula for calculating the maximum pressure on the screw:

$$Pmax = \frac{6\pi DNL\eta \cot A}{dc^2}$$

Where:

Qd = volumetric flow rate (m³/s)

D = outer diameter of the screw (m)

N = rotational speed (rpm)

dc = channel depth (m)

sinA and cosA = functions of the helix angle

Calculations:

For the modified screw:

$$Pmax = \frac{6 \cdot \pi \cdot 0{,}04 \cdot 38 \cdot 0{,}22 \cdot 100 \cdot 2{,}35}{0{,}012^2} = 10286621\ Pa = 10{,}2866\ MPa$$

For the unmodified screw:

$$Pmax = \frac{6 \cdot \pi \cdot 0{,}037 \cdot 38 \cdot 0{,}22 \cdot 100 \cdot 2{,}35}{0{,}01^2} = 9515124\ Pa = 9{,}5151\ MPa$$

Where:

Pmax = maximum pressure (Pa or MPa)

D = outer diameter of the screw (m)

N = rotational speed (rpm)

L = metering length (m)

h = viscosity (Pa·s)

dc = channel depth (m)

cotA = cotangent of the helix angle

3.2 Presentation of Research Results

a. Results of the Modification Design

Below is the image of the new screw design:

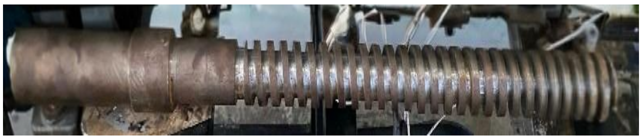

Figure 6. Modified Screw

After completing the screw modification process, data were collected using the previously existing plastic extruder machine. The data collection process for the filament involved the following steps:

- Reinstall the screw into the plastic extruder machine.
- Power on the plastic extruder machine using the following operational procedure:

- Ensure the machine is plugged into a power source.
- Turn on the heater via the control panel on the machine.
- Set the heater temperature to the desired level.
- Wait approximately 30–60 minutes for the temperature to stabilize.
- Once the desired temperature is reached, start the motor using the thermostat control.
- Load an adequate amount of material through the hopper.
- Close the hopper cover.
- Wait for the material to exit through the output port.
- Allow a few seconds for the filament to extend into the cooling bath.
- Guide the cooled filament into the puller roller.
- The filament exiting the puller roller is then fed into the winding roller or stored. Continue until the process is complete.

■ Filament data are recorded at three different temperatures: 110ºC, 120ºC, and 130ºC. For each temperature, data are collected for 1 minute and then analyzed (see Tables 2 and 3 below).

b. Filament Data Collection Results

Table 1. Machine Specifications

No.	Specification	Information
1	Screw Rotation	38 Rpm
2	Heater Power	450 watt
3	Machine Capacity	0,5 kg/jam
4	Type of Heater	Electric Heater
5	Drive Motor	1 Phase Motor
6	Supported Filament Material	PLA (polylactic Acid)
7	Control System	Autonics
8	Cooling System	Air or Water Cooling

The filament data were collected using PLA (Polylactic Acid) at three different temperatures: 110ºC, 120ºC, and 130ºC, and the results from the old screw were compared with those from the new screw. The machine specifications used during data collection are as show in table 1.

Table 2. Old Screw Data

No.	Documentation result
1	 110º C, 179 cm

Analysis: the test results at 110°C revealed numerous defects, including an inconsistent filament diameter exiting the nozzle and an uneven surface.

2	 120º C, 279 cm

Analysis: the test results at 120°c revealed several defects, including a small diameter of the filament exiting the nozzle, an uneven surface, unstable extrusion from the nozzle, and brittleness. this may be due to delays in feeding the pla pellets, which caused gaps to form within the screw.

3	 130º C, 333 cm

Analysis: the test results at 130°c exhibited many defects, such as a small diameter of the filament exiting the nozzle, an uneven surface, and brittleness. this may occur because the high temperature causes the material to melt too quickly and exit the nozzle prematurely.

Overall analysis: the filament produced using the old screw turned black because the pla material remained in the barrel for too long due to the gap between the barrel and the screw diameter. this gap resulted in insufficient pressure from the old screw, causing the pla pellets to become trapped in the barrel and eventually char (turn black). in addition to discoloration, this also led to the filament becoming brittle, making it unsuitable for use in 3d printing.

Table 3. New Screw Data

No.	Documentation result
1	

110º C, 247 cm

Analysis: the results obtained at 110ºc using the new screw were quite good, as expected, with an average diameter of 1.7 mm to 1.75 mm. although the filament produced was not perfectly round, the dimensions achieved were in line with the desired specifications.

2	

120º C, 285 cm

Analysis: the results obtained at 120ºc were suboptimal because the high temperature used caused the resulting diameter to be smaller, with an average diameter of 1.5 mm.

3	

130º C, 340 cm

Analysis: similar to the results at 120ºc, the test at 130ºc produced even poorer outcomes due to a smaller diameter, with an average diameter of 1.3 mm, rendering it unsuitable for 3d printing.

Overall Analysis: from the results of observation during the process of taking pressure data produced from the modified screw, it is better that it can occur because of the change in diameter and pitch change in the modified screw. The results of data collection using a new screw get quite good results, where the filament produced becomes white and not brittle. In addition to the screw design, there are also other factors that affect the filament that The resulting is temperature, cooling, screw rotation and the process of filling PLA (polylactic acid) seeds. At the time of the data collection process, it was carried out following the existing engine design except that the screw rotation speed was changed from 24 rpm to 38 rpm. The medium 38 rpm speed that is often chosen in this plastic extruder due to its small to medium production, provides a balance between output capacity, melting time and mixing homogeneity as well as the risk of shear overheating. In addition, adjusted to the thread geometry of the aggressive thread design added high speed equal to the risk of local overheating and burn marks. Overheating can occur if the material is high viscosity (HDPE), the barrel cooling system is not optimal and the thread design produces too much friction. The interaction between temperature and screw speed should be optimized together, not separately. The goal is homogeneous melting, non-damaging shear, and proper cooling. Poor process parameters will result in brittle, inconsistent or even total failure in 3D printing or other applications. Theoretically, this increase in dimensions expands the volume of the material conveying line which directly increases the *drag flow* capacity. As explained by [26] the volumetric flow rate in a single-screw extruder is directly proportional to the square of the diameter and the magnitude of the *pitch* angle. This is proven experimentally by increasing the flow discharge from 0.000921 m^3/s to 0.00129 m^3/s and increasing the maximum pressure reaching 10.2866\ MPa. This increase in pressure is crucial to ensure uniform melt density before it comes out through the *nozzle*. The use of PLA (*Polylactic Acid*) material at 38 rpm produces a filament that is pure white and not brittle. These physical qualities indicate that the design modification manages to achieve high melt homogeneity without triggering thermal degradation. According to [28] PLA is a polymer that is very sensitive to heat; stable pressure helps prevent the formation of air cavities (*voids*) which are often the cause of irritation in the final product. The selection of a speed of 38 rpm also plays an important role as a balance point between the output capacity and the dwell time of the material in the barrel. [29] Stated that shear speed optimization is necessary to prevent *viscous dissipation* or overheating due to internal friction. With a more aggressive thread design, proper speed regulation ensures that heat remains under control so that the risk of *burn marks* can be avoided, in accordance with the bioplastic processing principles put forward by [30] Overall, the synergy between screw geometry modification and precision of operational parameters has been proven to yield optimal outputs for advanced applications such as 3D printing filament.

4. Conclusion

The machine tested in this study was a single-screw extruder with an L/D ratio of 1:10, featuring a screw diameter of 40 mm and a length of 400 mm. The research results demonstrate an increase in pressing force, flow quality, and filament quality when using the modified screw compared to the unmodified version. The modified screw produced white filament, whereas the old screw yielded black filament. The black color in the old screw filament is attributed to suboptimal pressure within the barrel, which hindered material transport to the nozzle and resulted in excessive residence time, leading to burning. In contrast, the modified screw improved the flow quality within the barrel, resulting in better filament characteristics.

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