International Journal of Advances in Engineering and Management (IJAEM)
Volume 4, Issue 7 July 2022, pp: 360-369 www.ijaem.net ISSN: 2395-5252

Design and Fabrication of Filament Winder for Twin Screw Extruder

[1]vijayvignesh N S
[1]M.E. Manufacturing Engineering, Anna University, MIT Campus, Chennai, Tamil Nadu 600044, India.

Submitted: 01-07-2022 Revised: 04-07-2022 Accepted: 08-07-2022

ABSTRACT: The research project is about the design and fabrication a winder setup so as to produce filaments of uniform diameter and without any breakage under constant tension from a twin screw extruder which are used as raw material for fused deposition modeling (FDM) machine. In addition the extrusion of PLA filament has been done using the twin screw extruder at optimized extruder zone temperatures and the effect of speeds of extruder and winder upon filament diameter has been studied. The customized filaments of varying diameters (1 mm - 1.75 mm) extruded, are within the standard tolerance (±0.05mm) and hence can be used for filament extrusion of FDM application.
KEYWORDS: Design and fabrication, Filament extrusion, Twin screw Extruder, 3D printing, Customized 3D printer filament production.

I. INRODUCTION

Twin screw extruder is a machine having two parallel rotating screws mounted in a same barrel and rotates either in the same or opposite directions based on the drive arrangement. They are used for crushing and mixing of materials. They provide a more uniform flow of the material through the barrel, as compared to single screw extruder, due to the positive pumping action [1]. They are typically more flexible and efficient due to the twin action. Twin screw extruder, as shown in Figure 1, consists of a hopper to feed in the matrix material and a separate cup to add fillers if required. It also consist of 6 heating zones, whose temperatures can be independently altered and whose optimization determines the efficient mixing of the materials along with constant monitoring of speed of the twin screw extruder. A water bath is to be provided at the outlet of the extruder in order to quench the semi-molten product which when pulled at constant speed produces filaments of uniform diameter.

Figure 1. Twin Screw Extruder

Fused deposition modeling (FDM) is a 3D printing technology that uses melt extrusion method, where the filaments (Standard diameter: either of 1.75 mm or 2.85 mm and Standard Tolerance: ±0.05mm) are subjected to localized heating at the tip of the extruder nozzle which melts the filament that are deposited on the FDM bed, coated with silicone gel or concealed with masking tape, the desired design or pattern is printed layer-by-layer until the entire product is built [2] as shown in Figure 2.FDM printers mean a low cost-to-size ratio and materials which are capable of being utilized are extruded as filaments and having their melting temperature below 260 °C. The main disadvantage of FDM-3D printing is its low resolution, it’s not ideal for parts with minute details and the products will likely have rough surfaces and require post-processing to achieve a smoother finish.

International Journal of Advances in Engineering and Management (IJAEM)
Volume 4, Issue 7 July 2022, pp: 360-369 www.ijaem.net ISSN: 2395-5252

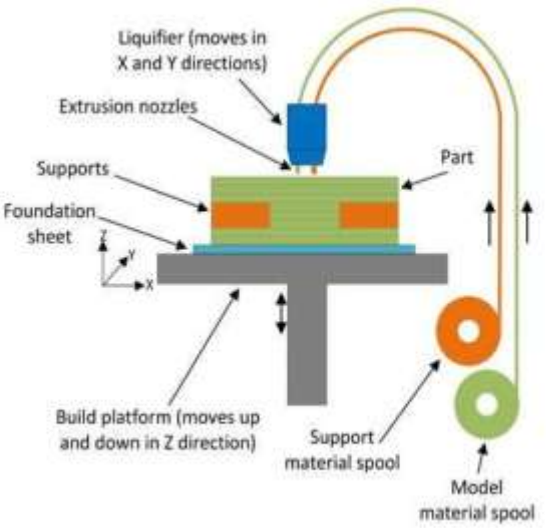


Figure 2. Fused Deposition Modeling (FDM) Machine

The counter rotating twin screw extruder used in our study is a segmented left handed rotational tool in operation. The average shear rate experienced by the materials in a twin screw extruder by considering shear rate as a function of the screw geometry, feed rate, and screw speed and the extent to which they affect the materials. It was found that, under same operating standards, the shear rates of the left-handed rotation are always higher than those of the right-handed rotation [3].

The non-Newtonian and non-isothermal flow in co-rotating and counter-rotating twin screw extruder systems are based on parameters such as screw speed, screw pitch, rotating direction, deformation rate, residence time distribution, the average strain. It was observed that the high screw speed and small screw pitch increases the dispersive mixing, and distributive mixing performance respectively. Conveying and distributive mixing performance was better found in co-rotating screw extruder than in counter-rotating screw extruder with the same screw speed and pitch [4].

The effect of extrusion temperature and deposition speed on fusion between single quanta of polymer has shown that the extrusion temperature has more influence when the deposition speed is low, while the duration of contact at the interface has a bigger effect at the higher speed [5].

II. 2. DESIGN AND FABRICATION

2.1 Conceptual Design

The conceptual design of the filament winder for the twin screw extruder is as illustrated in Figure 3. The winder base is similar to a chassis in automobiles to which every other component is mounted upon. The idler setup used is similar to standard S-type arrangement used in textile industries [6] so as to provide a suitable and constant tension to the filament. The spool setup includes a shaft to hold the spool, ball bearings to provide smooth rotation and winder housing to hold the setup to the base by providing the axis line for the filament winding. The filament guide which is manually operated is used to evenly distribute the filament wounded on the spool through its width.

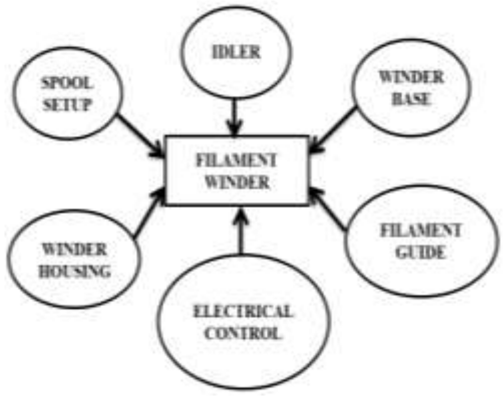


Figure 3. Conceptual Design of Filament Winder

2.2 Electrical Control of Winder

The schematic electrical circuit diagram of the winder setup is as shown in Figure 4. The electrical circuit has been fabricated to serve the purpose of controlling the speed and direction of rotation of the Direct Current (DC) gear motors via a potentiometer which is powered by the Switched Mode Power Supply (SMPS).

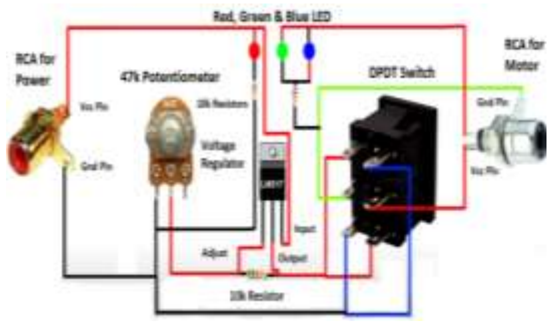


Figure 4. Electrical Circuit Schematic Diagram

The integrated circuit L298 2A Dual Motor Driver Module with PWM Control, as shown in Figure 5 along with the port details, is used to control the speed and direction of the DC gear motor. Connections are then made to the

International Journal of Advances in Engineering and Management (IJAEM)
Volume 4, Issue 7 July 2022, pp: 360-369 www.ijaem.net ISSN: 2395-5252

switches such that the two gear motors can be independently operated under both the functional aspects. The completely fabricated electrical circuit is as shown in Figure 6.

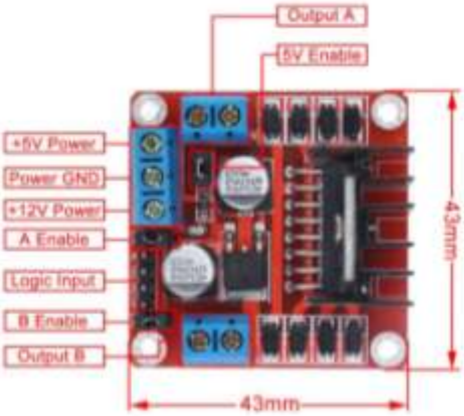
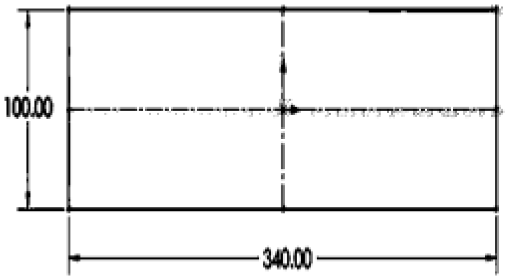
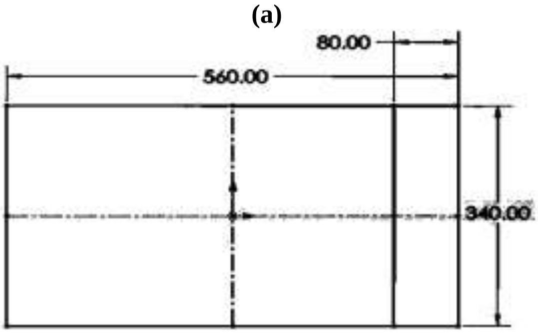


Figure 5. L298 2A Dual Motor Driver Module with PWM Control

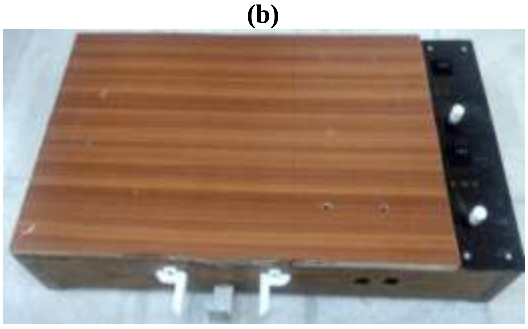
Figure 6.Fabricated Electrical Circuit



(a)



(b)



(c)

Figure 7. (a) Side View (b) Top View (c) Fabricated Winder Base

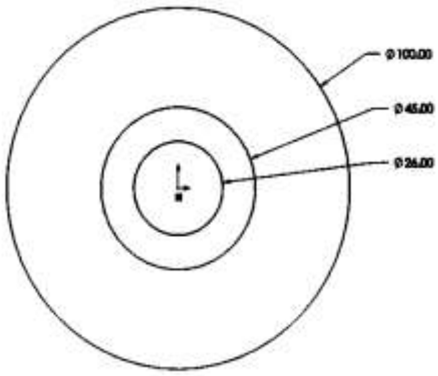
2.3 Mechanical Parts Fabrication

2.3.1 Winder Base

The base of the winder is made of teak wood and the platform is made of plywood. A separate provision has been made in platform to accommodate the L298 Driver Module and DPDT switch to control the motors, clamp setup to hold the DC battery and/or SMPS, the spool housing and the idler housing appropriately bolted to the base and a provision to guide the filament around the spool in a uniform manner. The winder base and its dimensions are illustrated in Figure 7. All the specified dimensions are in mm.

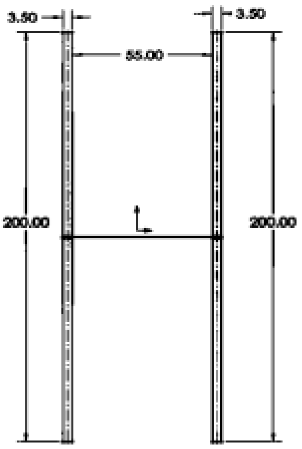
2.3.2 Spool

The spool that has been used is the one that is commercially used to wind the filaments used for 3D Printing process. The spool and its dimensions are illustrated in Figure 8. All the specified dimensions are in mm.



(a)

International Journal of Advances in Engineering and Management (IJAEM)
Volume 4, Issue 7 July 2022, pp: 360-369 www.ijaem.net ISSN: 2395-5252



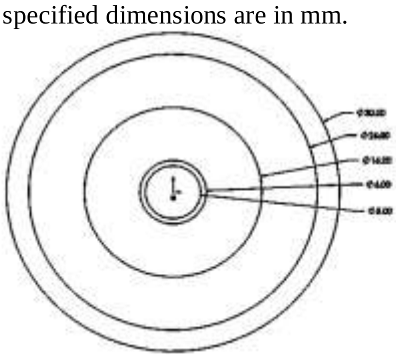
(b)

(c)

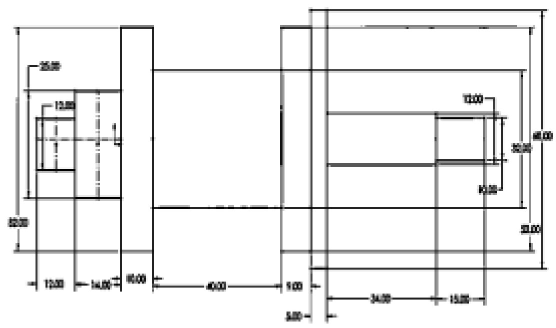
Figure 8. (a) Side View (b) Front View (c) Spool

2.3.3 Shaft

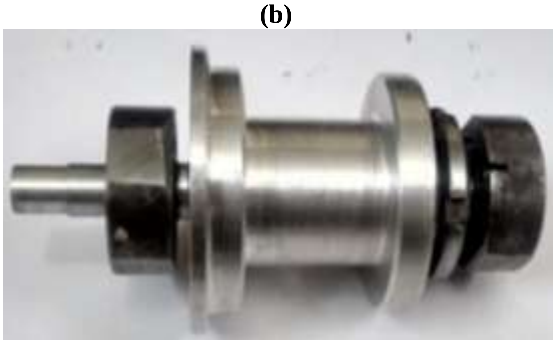
The shaft is made of lightweight Aluminum that has been processed through various machining processes such as turning, drilling and tapping in order to accommodate the ball bearings, winder motor through a coupler and spool. The shaft and its dimensions are illustrated in Figure 9. All the specified dimensions are in mm.



(a)



(b)

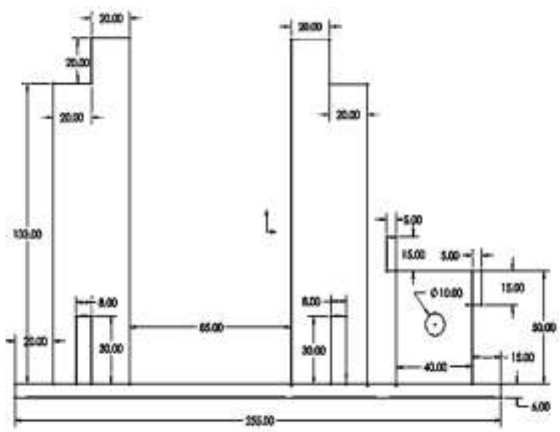


(c)

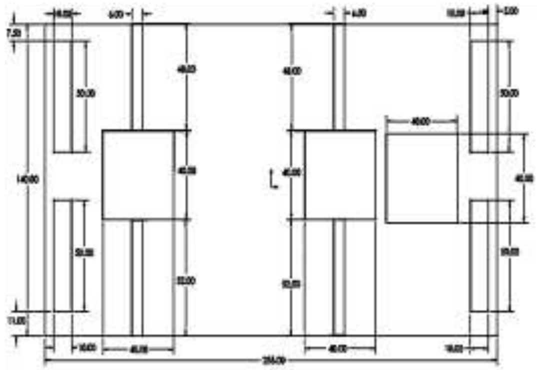
Figure 9. (a) Side View (b) Front View (c) The Fabricated Shaft

2.3.4 Spool Housing Base

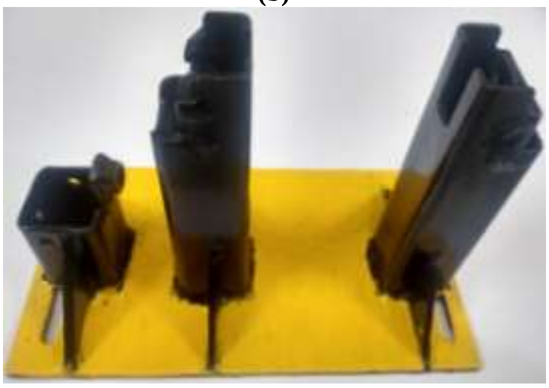
The spool housing base is made of Mild Steel material through machining processes such as slotting, arc welding, drilling and grinding. The spool housing base and its dimensions are illustrated in Figure 10. All the specified dimensions are in mm.



(a)



(b)

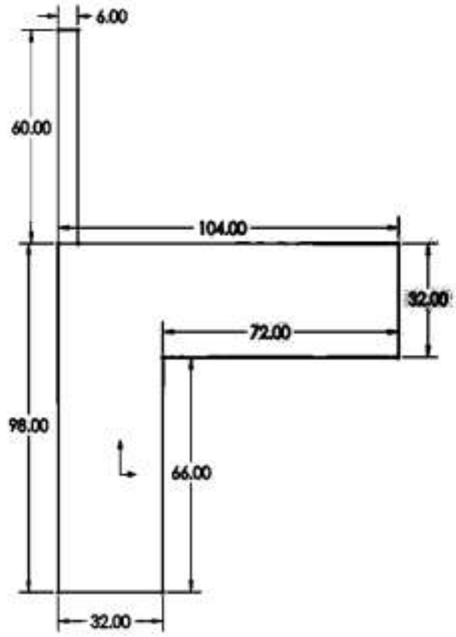


(c)

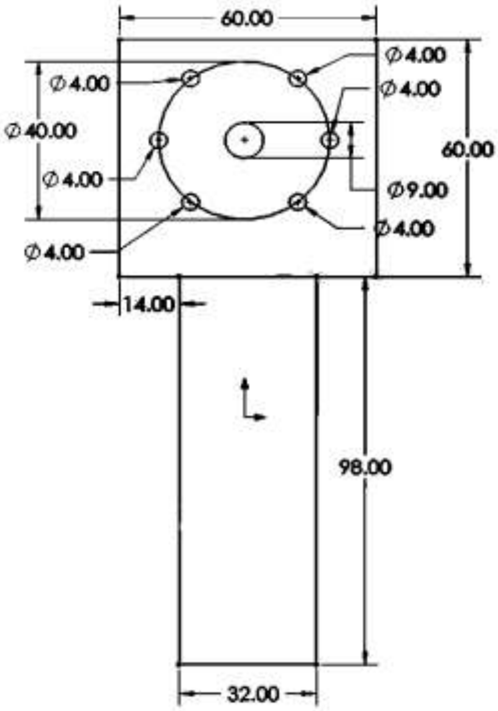
Figure 10. (a) Front View (b) Top View (c) The Fabricated Spool Housing Base

2.3.5 Winder Motor Housing

The winder motor housing is used to mount the 10 kg DC gear motor which is made of mild steel through machining processes such as arc welding, drilling and tapping. The winder motor housing and its dimensions are illustrated in Figure 11. All the specified dimensions are in mm.



(a)



(b)

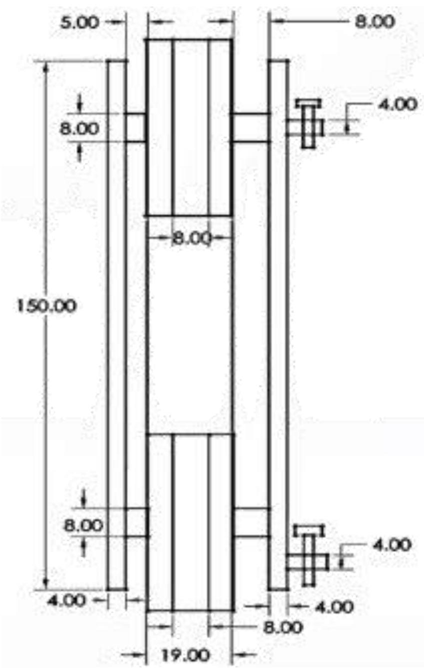
International Journal of Advances in Engineering and Management (IJAEM)
Volume 4, Issue 7 July 2022, pp: 360-369 www.ijaem.net ISSN: 2395-5252

(c)

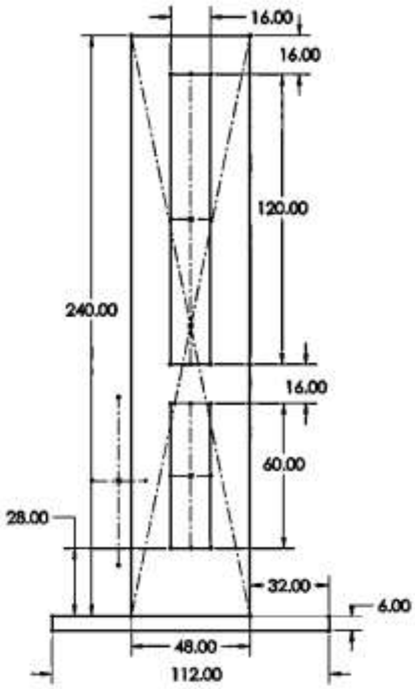
Figure 11 (a) Front View (b) Side View (c) The Fabricated Winder Motor Housing

2.3.6 Idler

The idler setup, as illustrated in Figure 12, is made of IS 2062 E250 Mild Steel square tubular decks and flat plates in order to ensure sturdiness which are held together by arc welding. Its high hardness and toughness can help in sustaining the vibration thereby nullifying the vibration produced by the coupled motor. The assembly would be such that the center line of action of all the parts lies on the same line as it would assist in obtaining constant tension and uniform distribution throughout. All the specified dimensions are in mm.



(a)



(b)

(c)

Figure 12 (a) Front View (b) Side View (c) Fabricated Idler Setup and Adjustable Holder

The other components used in the fabrication of spool housing are Ball Bearing 6001 (ID = 12mm ; OD = 28mm : W = 8mm), Threaded

International Journal of Advances in Engineering and Management (IJAEM)
Volume 4, Issue 7 July 2022, pp: 360-369 www.ijaem.net ISSN: 2395-5252

Lock Nut (Size M10), SS Bolt & Nut (Size M12), Allen Screw (Size M3 & M5) and Flexible Coupler(10mm to 6mm).

2.3.7 Assembled Winder

The completely assembled and functional winder setup with integration of hardware and electrical parts beside the twin screw extruder are as shown in Figure 13.

(a)

(b)

Figure 13. (a) Assembled Winder
(b) Alongside with Twin screw Extruder

III. 3. MATERIALS AND METHODS

3.1 Raw Material for Extrusion

Injection moulding grade PLA 3052-D obtained from Nature work is used as a raw material as shown in Figure 14. Properties of the PLA are listed in Table 1.

Figure 14. Raw PLA Pellets

Table 1. Properties of PLA

PROPERTIES	VALUES
Yield Strength	62 MPa
Specific Gravity	1.24
Melt Temperature	145-160 ^{o}C
Glass Transition Temperature	55-60 ^{o}C
Total Elongation	3.5 %
HDT(Heat Deflection Temperature)	55 ^{o}C

3.2 Twin Screw Extruder

Counter segmented rotating Twin Screw Extruder, as illustrated in Figure 15 and 16, is used for melt compounding of PLA which is capable of providing a more uniform flow of the product through the barrel and are typically more flexible and efficient due to the twin action. The raw PLA is fed into the hopper.The said extruder consists of 6 heating zones, whose temperatures and speed can be independently altered using the control panel, as illustrated in Figure 17, and whose optimization determines the efficient mixing of the materials.

Figure 15. Twin Screw Extruder

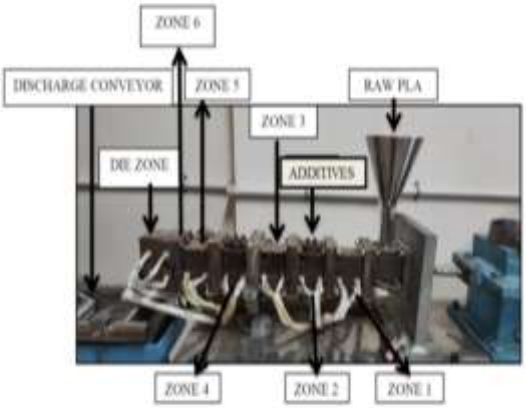


Figure 16. Segments of Twin Screw Extruder

The molten PLA is quenched in a water bath at the outlet of the extruder and collected as filaments through the winder setup. The optimized temperature used is as tabulated in Table 2.PLA is pre-heated in a hot air oven at 85 °C for 4 h in order to remove moisture. The PLA is then fed into the hopper after the extruder attains the set optimized temperature. The speed of the extruder can be varied so as to ensure the quality of the molten PLA, such as better mixing or to be drawn as filaments, received at the die zone. The experimental results of average filament diameter measured using vernier caliper with a least count of 0.1 mm, at a distance of 10 mm through 300 mm.

Figure 17. Twin Screw Extruder Control Panel

Table 2. Optimized Temperature Parameter Values of Twin Screw Extruder

EXTRUDER ZONES	TEMPERATURE (°C)
Zone – 2	150
Zone – 3	135
Zone – 4	155
Zone – 5	170
Zone – 6	165
Die Zone	150

IV. 4. RESULTS AND DISCUSSION

Table 3. Calculation of linear speed of filament from twin screw extruderparameters

S.No.	Parameter	Formula/Value
1.	Extruder Speed (N)	60 rpm
2.	Diameter of the Extruder Outlet (d)	2.25 mm
3.	Area of the Extruder Outlet (A)	πr^2 = 3.976 mm^2
4.	Channel Depth of Extruder (h)	2.4 mm
5.	Flow rate at the Outlet (Q)	**0.02258 x (d^2) x h x N** ≈ 16.469 mm^3/s
6.	Linear Speed at Outlet (v_o)	**Q / A** =4.142 mm/s
7.	Centripetal Force (F_C)	**(m x v_o^2) / R** = 1.956 N

Linear speed at the outlet is used as the winder speed so that there is a smooth drawing, hence no change in the filament diameter during the winding. Theoretically at this speed, we will be

International Journal of Advances in Engineering and Management (IJAEM)
Volume 4, Issue 7 July 2022, pp: 360-369 www.ijaem.net ISSN: 2395-5252

able to obtain the filament of 2.25 mm diameter, however in real time; there are many factors like back pressure, the molten polymer flow, and the quenching setup that does not allow for the exact extrusion as anticipated. The experimental results of average filament diameter measured using vernier caliper with a least count of 0.1 mm, at a distance of 10 mm through 300 mm have been tabulated in Table 4.

For a constant extruder speed, the diameter of the filament would decrease as the speed of the winder is increased considering the speed at the outlet of the extruder is maintained constant,

$\boldsymbol{dav}$-1

The experimentally obtained filament diameter values at various winder speed and extruder speed is in acceptance with the standard tolerance of ±0.05 mm. The existing Fused Deposition Modeling (FDM) machine in the laboratory uses filament diameter of 1.75 mm and a nozzle diameter of 0.4 mm. Filament of various diameters are obtained for customization based on the standard used in FDM machine extruder as it's specifically designed considering various factors to print products. Hence, for different extruder speeds and at various winder speeds the diameter of filaments obtained that would satisfy or be suitable for 3D printing alone is extruded. Distance between the Extruder Outlet and Winder, i.e length of filament wasted before uniform winding occurs,

(L) = 710 mm ; v_{max} (at 60 rpm) = 0.283 m/s.

Since the centripetal force imparted is approximately 1/6th of breaking tension of 1.5 mm diameter PLA filament (12.57 N), the effects due to strain induced will be negligible and there will be no breakage.The filament of the varying diameters in the range of 1 mm to 1.75 mm has been made possible by varying the speeds of twin screw extruder (40 rpm - 70 rpm) in steps of 5 rpm and that of filament winder setup (15 rpm - 20 rpm) in steps of 2 rpm and a quenching bath at room temperature.

Table 4. Effect of Extruder and Winder Speed on Filament Diameter

S. No.	Extruder Speed (rpm)	Winder Speed (rpm)	Avg. Filament Diameter (mm)
1.	40	15	1.55
		17	1.40
		20	1.15
2.	45	15	1.65
		17	1.38
		20	1.17
3.	50	15	1.65
		17	1.40
		20	1.21
4.	55	15	1.65
		17	1.38
		20	1.22
5.	60	15	1.68
		17	1.38
		20	1.23
6.	65	15	1.75
		17	1.59
		20	1.53
7.	70	15	1.75
		17	1.62
		20	1.55

V. CONCLUSION

The design and development of filament winder to collect filaments of uniform diameter and without any breakage from a twin screw extruder has been accomplished. Effect of extrusion speeds of winder and extruder on the diameter of PLA filament has been studied at optimized temperature in identified process window of extruder zones wherein increase in speed of the winder for a constant extruder speed decreases the filament diameter.The diameter of PLA filaments so produced are within the standard tolerance of the extruder of FDM machine range (±0.05 mm) and hence suitable for customized 3D printing application.

VI. FUTURE SCOPE

To further improve the dimensional tolerance of the filament obtained, micro adjustment of winder speed with feedback

Volume 4, Issue 7 July 2022, pp: 360-369 www.ijaem.net ISSN: 2395-5252

mechanism can be established. A more sophisticated quenching arrangement of varying lengths and temperature baths can be implemented to study its effects upon the quality of filament extruded.

REFERENCES

[1]. Sunday, S.S., Oluwafemi, A. A. and Janet, A. A. (2017), "Development of a twin screw extruder", CIGR Journal, Vol. 19, pp: 181 - 186.

[2]. Aboma, O. A., Masood, S. H. andBhowmik, J. L. (2018),"Optimization of fused deposition modelling process parameters: A review of current research and future prospects", Advances in Manufacturing, Vol. 3, pp: 42-53.

[3]. Vergnes, B. (2021),"Average shear rates in the screw elements of a co-rotating twin-screw extruder", Polymers, Vol. 13, pp: 1-12.

[4]. Kim, N., Kim, H. and Lee, J. (2006),"Numerical analysis of internal flow and mixing performance in polymer extruder II: twin screw element". Australian Rheology Journal. Vol. 8, pp: 1-11.

[5]. Yin, B., He, Q., and Ye, L. (2021), "Effects of deposition speed and extrusion temperature on fusion between filaments in single-layer polymer films printed with FFF", Advanced Industrial and Engineering Polymer Research, https://doi.org/10.1016/j.aiepr.2021.07.002

[6]. Kulinowski, P., Kasza, P.,&Zarzycki, J. (2021), "Influence of Design Parameters of Idler Bearing Units on the Energy Consumption of a BeltConveyor", Vol. 13, pp: 437-445.