

Workspace calculation for 3D printer based on the transformation matrices and direct kinematic modeling by using screw based extrusion¹Pankaj Kumar, ²Sandeep Kumar Jhamb¹Assistant professor, Mechanical Department, Arya Institute of Engineering & Technology, Jaipur, Rajasthan, India²Associate Professor, Mechanical Department, Arya Institute of Engineering & Technology, Jaipur, Rajasthan, IndiaE-mail: ¹pkumar9252@gmail.com, ²rpsjhamb@gmail.com**Abstract**

Extrusion-based 3D printing is a common additive manufacturing process for the manufacture of plastic prototypes and a single or a small series of functional products. The most common extrusion-based technique is fused deposition modeling. Although this is a general 3D printing technology, end users have some limitations. The main limitation is the lack of commercial availability of materials. In addition to this, the feed must be a filament with a narrow tolerance compared to the nozzle diameter which prevents blocking of the nozzle. A limited range of materials dislikes many end users to manufacture parts by filament extrusion 3D printing. This will develop screw-based extrusion with 3D printers. This work deals with 3D printer workspace calculations based on transformation matrices and direct kinematic modeling. Rheological parameters (shear stress, pressure drop) are also determined using ANSYS POLYFLOW and are useful for assembly design and manufacture.

Keywords: Additive Manufacturing, Extrusion Based 3D Printing, Workspace, ANSYS POLYFLOW.**Introduction**

Recently, the development of rapid prototype technology has progressed and there is a practical prospect of using additive manufacturing in the health field, especially in the complex shape, especially in the fields of tissue and bone engineering. The term rapid prototyping (Rapid Prototyping, RP) is widely used in the industry to describe the process of quickly creating a system or component at the stage just before the final product or before commercialization. The American Society for Testing and Materials Testing (ASTM) defines Additive Manufacture (AM) as "a process of combining materials for creating objects from three-dimensional model data on layers, as opposed to subtractive manufacturing" You can use (ASTM, 2010). Commercial AM machines generally require a large amount of material to start work and manufacture parts. In addition, there are operational restrictions settings, and it is configured to use proprietary materials from suppliers and manufacturers. These constraints impede the advancement of research fields including material development and processes. Under such circumstances, technology development with open source 3D printers with reduced dimensions is interesting because there is less raw material and more flexibility in software and hardware development. Another motivation for this job is expansion of the market associated with desktop 3D printers and there are three brands using various materials and vapor deposition technology.

The most commonly used techniques used in desktop 3D printers include: Fused Deposition Modeling (FDM) Commercial Processes Raw materials are considered thermoplastic and fed in the form of flexible filaments that are wound into rolls. The filament is introduced into the head by an integrated digital control device that controls the

filament, which feeds the wire material and pushes it into the heating channel, causing it to melt and squeeze through the nozzle at the other end of the channel. Other techniques use syringe extrusion, which occurs by compressing the material in the deposition chamber and subsequently extruding the material through the needle [1]. Polymer processing in the extruder involves the use of any kind of solid material entering the extrusion screw, melting and rotating by the screw until the end of the course [2]. The single screw or twin screw extruder design is the most common configuration in industrial polymer processing. The study of flow behavior of non-isothermal fluids in the field of fluid dynamics was performed using ANSYS, and the shear rate and pressure distribution were determined in the application of larger diameter screws [3]. Covas et al. developed a mini-extruder and analyzed the thermo-mechanical properties comparable to the thermomechanical properties of large machines [4]. Brankeer et al. developed a micro screw extruder under the open source network and used waste plastics for 3D printing [5]. Chakraborty et al. A new method called the curved layer FDM (CLFDM) has been developed, which focuses on the use of screw extrusion to create thin-walled curved parts [6]. Valkenaers et al. developed a screw-based extrusion 3D printer, a syringe-based 3D printer and compared it with the FDM process [7]. Silveira et al. used a functional prototype 3D printer with interchangeable heads and analyzed using SEM. [8]

Workspace Calculation

Workspace calculations are crucial for any type of robotic machine. The workspace represents the portion of space around the base of the manipulator that the arm endpoint can access. The shape and size of the workspace depends on the configuration of the arm, the structure, the degree of freedom, the size of the link, and the design of the joint. The physical space (with wrists and end effectors) that can be scanned by the manipulator may be more or less than the arm endpoint workspace. The volume of the scanned space is called workload; the surface of the workspace describes the workspace. The gantry Cartesian configuration is used here. This is the simplest configuration of all three prismatic joints. It consists of three major axes. There are upper and lower limits for the movement of each link. So the endpoints running in the cube workspace. In order to calculate the workspace, the printer's frame allocation was created. The frame allocation describes the position of the end effector relative to the basic frame and from this the D-H parameters are calculated to form the printer's transformation matrix. These transformation matrices form the position and orientation of each link relative to the basic frame. The workspace here is obtained by solving the transformation matrix in MATLAB.

Transformation matrix w.r.t. Base frame

$$POS1 = {}^1T_0 = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & d_1 \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad (1)$$

$${}^2T_0 = POS2 = \begin{bmatrix} 1 & 0 & 0 & a_2 \\ 0 & 0 & 1 & 0 \\ 0 & -1 & 1 & d_1 \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad (2)$$

$$POS3 = {}^3T_0 = \begin{bmatrix} 1 & 0 & 0 & a_2 \\ 0 & 0 & 1 & d_3 \\ 0 & -1 & 1 & d_1 + d_3 \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad (3)$$

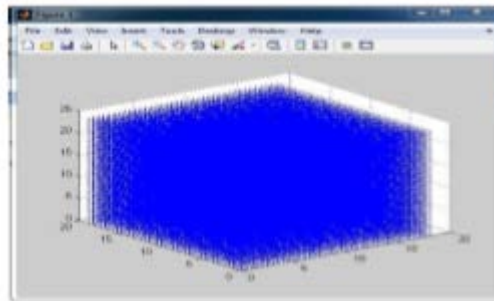


Fig. 1. Workspace calculation on MATLAB

The base part is 20 inches, horizontal X movement length is 25 inches and vertical motion of bed is 25 inches. The parameters for workspace analysis are considered based on the possible area to be covered using translational length of various joints. The workspace is shown in Figure 1.

Simulation of Flow through Extruder

The single screw extruder geometry was created using SOLIDWORKS. Figure 2 depicts the drawing of the extruder. The material flow is represented by the space between the screw and the extruder wall. Once the Solid Works drawing is created, the elements in the simulation are meshed with ANSYS WORKBENCH 14. Because of the small size of the extruder, triangular elements are used to represent three-dimensional modeling. The boundary area including the volume element includes (1) inflow 1 (outflow point), outflow 2 (outflow exit), wall 3 (screw surface) and wall 4 (extruder inner surface). Next, the volume element of the area between the boundary surfaces is designated as Fluid1, which corresponds to the simulated area, and the screw and wall area are designated as Solid2, indicating a fixed solid plane. Figure 3 shows the grid of volume elements.

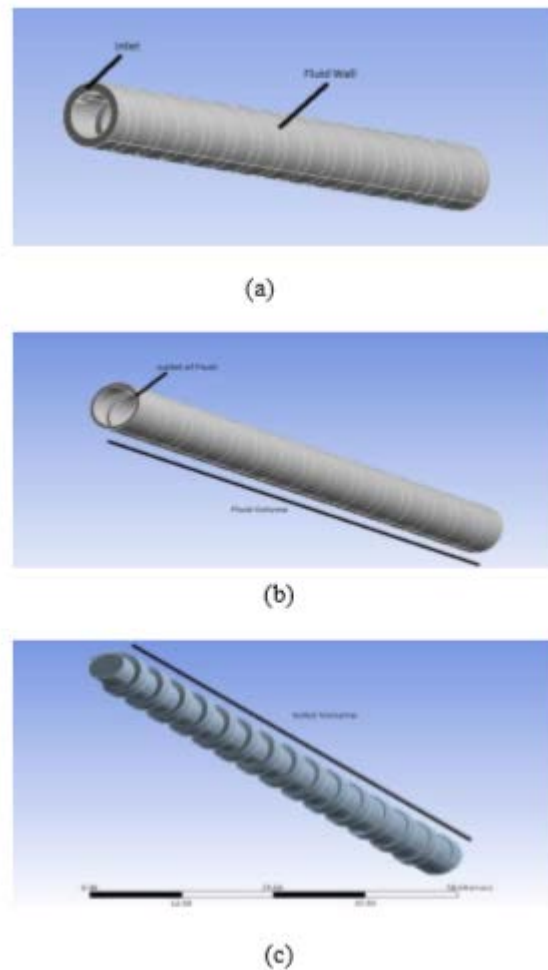
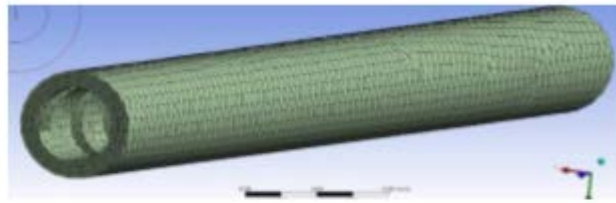
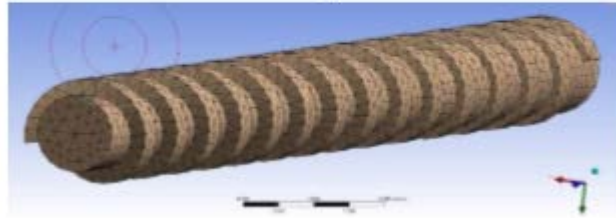


Fig. 2. Drawing of Extruder

once the volume element is created, the file is transferred to polyflow and converted to a polyflow formatted mesh file using ansys polyflow 14. the new task is created and set as an fem (finite element method) task, and as the steady state problem in the polydata section of ansys, the generalized newton non-isothermal flow problem is selected in the subtask box, and subtasks and subdomains are created area. in the material data frame, the choice of shear rate dependence of viscosity includes constantviscosity, bird-carreau's law, power law, bingham's law, herschel-bulkley's law, cross law, logarithm law, improved herschel-bulkley's law. , cross logarithm, modified bingham's law, improved herschel-brauli's law, carreauyasuda's law, and modified crossing law. in this preliminary study, this value was set as a power law because of its simplicity and better result method. finally, the flow boundary condition is specified as an inflow with a given flow rate and is applied as an outflow applied speed. Simulation results using cfd-post 12.0.1 display.



(a)



(b)

Governing equations

For a generalized Newtonian flow, POLYFLOW solves the Navier-Stokes equations, the mass conservation equation, and (for non-isothermal flows) the energy equation.

a. Navier-Stokes equation

$$H(v - \bar{v}) + (1 - H)(-\nabla p + \nabla \cdot T + \rho g - \rho a) = 0 \quad (4)$$

H is a step function, v is the velocity, $\bar{v}$ is the local velocity of moving parts, P is pressure; T is the extra tensor, ρg volume force, acceleration term. Extra tensor is define as ,where μ is viscosity, $\dot{\gamma}$ shear rate, T is temperature, D is rate of deformation of tensor.

b. Mass conservation equation-

$$\nabla \cdot v + \frac{\beta}{\mu} \Delta p = 0 \quad (5)$$

Where Relative compression factor, μ local viscosity.

c. Energy equation

$$0 = (1 - H)(\rho_f c_{pf} \frac{DT}{Dt} - r_f - T \cdot \nabla v - \nabla \cdot (k_f \nabla T)) + H(\rho_s c_{ps} \frac{DT}{Dt} - r_s - \nabla \cdot (k_s \nabla T))$$

d. Shear rate dependence model

$$\mu = k(\alpha \dot{\gamma})^{n-1} \quad (6)$$

Where, k is consistency factor (120000)

α = reciprocal of shear- rate (2500)

n = power law index (0.28)

e. Input Parameters

As input data for this purpose screw rotation speed 204 rpm material properties of extruder and melting material and for thermal boundary conditions temperature at inlet 298 K and temperature at outlet 533K are given.

Results and Discussion

- A. Local shear rate at inlet At the inlet only solid zone is formed so that viscosity is not significant in addition to it friction is generated because of breakage and rearrangement of molecular at screw edge, therefore strong phenomena of shear force is applicable here and as a result higher shear rate at flight tip is formed.
- B. Local shear rate at outlet Here the fluid section is developed with an elevated temperature and hence viscosity becomes significant. Fluid channel starts to become narrow at the outlet because it is the ending of screw flight so that shear rate reaches to its maximum.

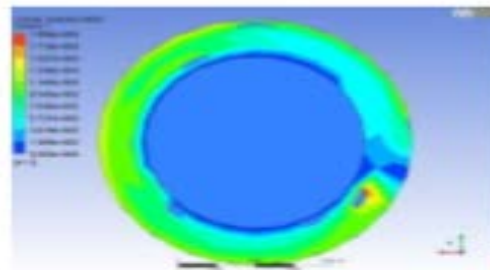


Fig. 4. Shear rate at Inlet

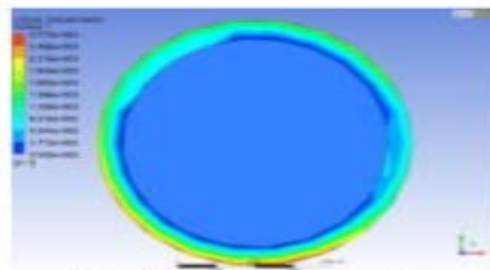


Fig. 5. Shear rate at Outlet

C. Inlet velocity

At the inlet channel material enters in circular path where at the periphery of circular path velocity is obtained zero because it is considered as no slip condition at wall and maximum velocity is achieved at middle of the portion. As earlier described, some hindrance is formed at inlet zone so that velocity magnitude is smaller as compared to the other sections.

D. Outlet velocity

At the outlet condition material totally converts to fluid and no center point is formed around which flow should generate because it is not a fully developed flow. From the results it is found that maximum velocity is achieved only in this section and this justifies that material is flowing in the downward direction.

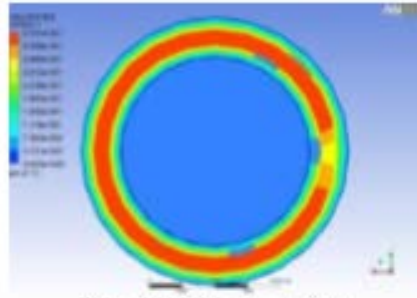


Fig. 6. Velocity at Inlet

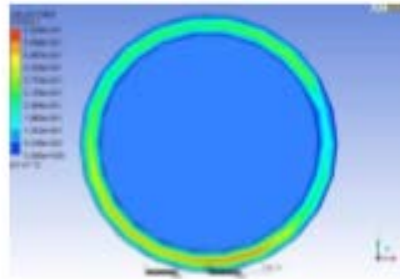


Fig. 7. Velocity at Outlet

Non homogeneous flow is developed and small high shear rate zone is generated at inlet and shown by red area. Inconsistency of flow causes to lower shear rate and it is increased later as soon as the flow is developed. Maximum shear rate at outlet can be observed as red area and where fluid is leaving to screw surface. A circular blue zone at inlet and outlet velocity defines the zero velocity of flow while at center red section shows the maximum velocity at center zone. Small yellow section shows the less velocity at inlet because of hindrance created in the start of flow while a centered red line at the end of flow in outlet velocity shows the maximum velocity achieved at the extreme outlet zone.

Conclusions

Therefore, the behavior of the material with shear rate and speed can be obtained by simulating the material flow at the inlet and outlet of the extruder. More research is needed to induce the influence of changes in shear rate and viscosity of the fluid on the development of internal shear stress in the screw extruder. This will help to more accurately design 3D printed extrusion equipment. In addition, the development of a viscoelastic model based on spiral extrusion 3D printing is essential for predicting flow.

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