

An ANSYS Software Analysis of Different Nozzle Exit Geometries of FDM Machine Nozzle

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Abstract: *Fused deposition modeling (FDM) is process of Additive Manufacturing which can generates 3D object from CAD model imported from any of CAD software. It is process in which semi-molten viscoelastic fluid extruded out from heated nozzle tip in pre- defined direction. After the deposition of semi-molten material on platform its temperature starts to be reduced, solidifies and bonding between surrounding filament become stronger. The purpose of this study to investigate the effect of various nozzle exit geometries such as square and triangular, on melt flow properties and temperature distribution of filament of ABS material during deposition process. To analyze that effect and melt flow behaviour ANSYS ACADEMIC 19.2 version is used. All that analysis performed in ANSYS FLUENT. Velocity distribution, pressure drop and flow out of nozzle tip with different geometries are simulated.*

From the FLUENT results it is observed that the pressure distribution along the length and corners of nozzle is approximately uniform in case of square nozzle exit geometry compared to other two. Also in case of velocity it is seen that maximum value obtained for triangular exit than the other shape. But for optimization point of view square nozzle is better in case of pressure distribution and filament bonding.

Keywords: *Fused deposition modeling (FDM), nozzle exit geometries, CFD, pressure drop and velocity distribution solidification, flow characteristics.*

I. INTRODUCTION

Additive manufacturing is newly developed advanced manufacturing technique in which rather than removing the material, material is added in layer by layer form for making the object. Additive manufacturing also called Rapid Prototyping Technique, solid freeform fabrication, and 3D printing. The AM found its huge usage and popularity in hobbyist and customer market. FDM was founded and patented by Scott Crumop in 1988. He is founder of Stratasys Company in 1989 in Minnesota. From the all methods of additive mfg.[1] FDM is most widely used low cost, easy to used manufacturing technique Using FDM process any complex shaped part which is possible to model in any of CAD software is easily printed layer by layer directly form that CAD model. It is done by Deposition of thermoplastic material extruded form the orifice of nozzle. FDM process was divided in to two parts 1) Virtual part 2) Physical part.

In First Part the CAD solid model of in any of modeling software is created. After that CAD model is saved as STL format to make it in understandable by FDM machine software i.e., insight, Ultimaker etc. After that this STL file inserted in to FDM machine for making slice into the desired direction, selecting the input parameters for generation of support material, providing build direction, temperature adjustment etc. This pre-processed file of model and supports called Stratasys machine language (SML) file or CMB file for FDM machine. After this process this file is send to the FDM for making modeled object. This part called pre- processing[2].

In second part of FDM process feed stock filament of thermoplastic material form spool enters in to FDM liquefier head by rollers, in this semi- liquid state filament extruded out in ultrathin bead from the nozzle orifice on machine build table. This table moves in X and Y directions and nozzle with extruder head moves in Z-direction the table movement is done according to parameter setting which is done in virtual part of process. Based on the complexity of part shape support structure is generated. Accept from the manufacturing and design application of FDM it found its place in research and development sectors. It may include part quality- quantity improvement, new material development, and biomedical engg. Tissue engg Textile engg etc[3, 4].

Chua et al [5]studied that during solidification process, the filaments establish cross-bonding. The ‘road width’, defined as the mean distance between two adjacent filaments, is so maintained in the path planning of the extrusion head that the filaments develop a bridge between them, known as a ‘neck’ by the process of viscous sintering. The bonding responsible for these necks to grow within a layer may be termed as the ‘intra-layer bonding’. At the same time, as one layer is deposited over the other, since the temperature of the previously solidified layer is still high, excellent propensity exists for similar bonds to be formed between the filaments of the two successive layers and these bonds may be termed as ‘inter-layer bonding’. FDM has shown potential to be used for both prototyping and final part production through the direct or indirect route. In the context of final part production, it is crucial to study the evolution of the strength of FDM

parts, for which it is essential to link the part strength to the intra-layer and inter-layer bonds and neck size. Several researchers in the past have studied the effect of different processing parameters on the strength of the FDM parts [6].

II. LITERATURE SURVEY

Sukinder et al [7] nozzle in FEA first for 2D and after that is considered for pressure distribution and velocity Behaviour for FDM nozzle. For Analysis diameter of nozzle tip is varied from 0.2 to 0.4 mm. from this it is founded that maximum value is obtained for 0.2 mm nozzle. But for optimum condition 0.3 mm nozzle is selected because it gives better more consistent filament width for each layer. Also for each nozzle diameter geometric error may calculated. Lewicki et al [8] investigated on effect of addition of carbon Nano fiber into the pure polymer material. They analyzed uniaxial printed part with CNF composition. Higher resolution numerical simulation of arrangement of CNF in flow through nozzle analyzed. Also velocity simulation in CFD throughout the nozzle included from that obtained that maximum velocity at nozzle tip is approximately is 0.02 m/sec. Papon et al studied flow through square and circular shaped nozzle for analysing mechanical and surface properties. In this research work material is composite of CNF and PLA materials. Also SEM observation was done for test specimens.

Multi-physics and multi-scale model is considered by frank et al [9] to study the Advance Additive Manufacturing process. Also CFD simulation of filament flow from the nozzle exit to molten pool and from that solid-liquid problem is solved. Heller et al [10] consider study on the 2D stoke flow observation in FEA to evaluate FDM extrusion for large scale material deposition. In this case special attention given to the deposition of molten polymer material on moving platform. Form nozzle exit the shape of extruded polymer material is measured or calculated using free surface normal velocity minimization technique. Once boundary behaviour is computed for melt flow deposition process then resulting mechanical and orientation of solidified scaffold is calculated within printed bead zone. Ramanath et al [11] consider the study on melt flow behaviour of polymer- e- caprolactone (PCL) as FDM material. It is one of the biomaterial which are used in form of filament material. For investigating the MFB of model two methods are selected which are mathematical modeling and finite element analysis using ANSYS. from comparison of results of both methods concluded that pressure drop and velocity depends on flow channel parameters. Qian Sun et al [12] described analysis of heat transfer process during actual printing. Also sintering experiments also included in study to evaluate qualitative and dynamics of bond formation between polymer filaments cooling process in each layer simulated using ANSYS software. Y Zhou et al [13] investigated on temperature distribution among polymer filament in FDM process because it will affect mechanical properties, integrity and bond quality. To analyze temperature distribution non-linear behaviour of specific heat and thermal conductivity are considered because phase transformation and temperature variation included. For this study ANSYS APDL is used at different time. Furlong et al [14] investigated on thermo mechanical behaviour of FDM process by using conceptual and experimental methods. In this study moving boundary conditions for transient enthalpy formulation developed to predict heat distribution and temperature profile during deposition of material and this calculated and analyzed results are validated using experiments.

Kubota et al [15] gives information about flow properties of pure ABS material. To find out various floe characteristics different tests and experiments are conducted. From the measurement of results particular range of fluid properties are obtained. Gracia et al [16] analyzed nozzle with different divergent zones to evaluate the behaviour of fibre alignment at nozzle tip. These work done to identify nozzle geometry for isotropic behaviour of fibre alignment at nozzle exit of extruded material. From this study it is founded that all diverging nozzle in diverging zone, no random distribution of fiber and thus isotropic properties of fused component is obtained. Brenken et al [17] investigated on 2D heat transfer model of filament during layer formation on platform during material deposition process using COMSOL Multi-Physics software. By activating different layers at different time. For heat transfer, temperature distribution is simulated. In further study by Brenken et al [18] studied same concept for 3D filament formed by crystallization kinematics models and melting model to describe re-melting of layer which are already cooled on bead. This phenomenon is generated and simulated in Abacuses by activating each layer for different time to generate actual deposition process. Crystalline and temperature distribution for time step during deposition was simulated in this study. Y. Hao et al studied on development of mathematical model of flow of velocity which was generated by combining related theories of fluid mechanics. For this analysis, in ANSYS Fluent analysis of internal fluid flow field distribution of material, distribution of pressure throughout nozzle length and velocity flow of nozzle section considered in this study. After the No. of experiments, the optimum nozzle structure for food filament deposition developed.

III. MATERIAL PROPERTIES

In this research work, the analysis in ANSYS 19.2 is done using FLUENT. For pure ABS material selected for this research work. For ABS material following thermal and fluid properties are selected for ANSYS Fluent which are listed below. All these properties are selected after the reviewing no. of related research work

No.	ABS Properties	Range	Unit
1	Thermal Conductivity	0.188-0.335	w/mk
2	Sp. Heat capacity	1390- 1920	J/kgk
3	Density	1010-1210	Kg/m ³
4	Glass Temperature	88 -120	⁰ C
5	Viscosity	1.12 – 1.5	Kg/ms

TABLE 1 MATERIAL PROPERTIES

IV. CFD ANALYSIS FOR FLOW THROUGH DIFFERENT NOZZLE EXIT GEOMETRIES

The no of research work done for flow analysis, melting behavior, bond formation thermal analysis etc., for circular nozzle exit and also varying diameter of circular exit. But there is no work done on the flow and thermal analysis through the different exit geometries like square and triangular shape. In this research work comparative study of CFD analysis for circular, square and triangular shaped nozzle exit are included. First we may start from basic FDM nozzle exit geometry which is circular shape. The various material properties are taken from table 1. The velocity of material at inlet is considered from research paper is 0.0000384 m/sec and outlet pressure for material come out from nozzle is taken as atmospheric.

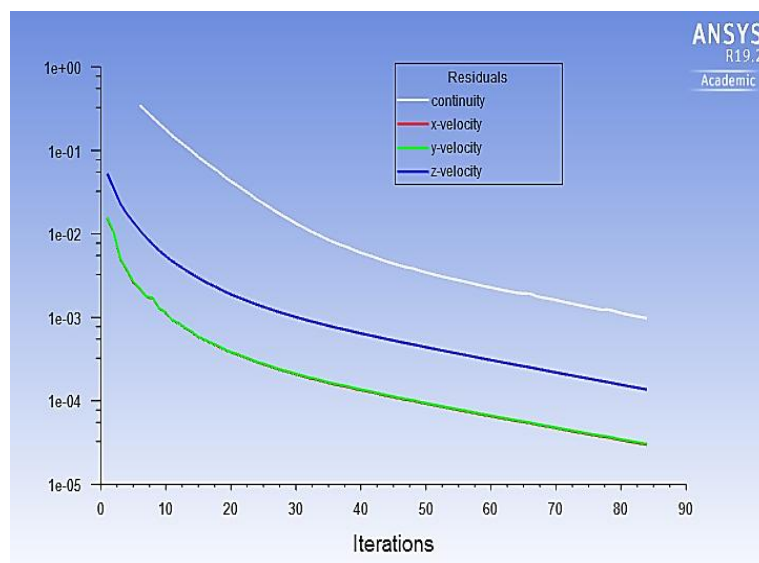


Fig. 1 Velocity behavior for all direction

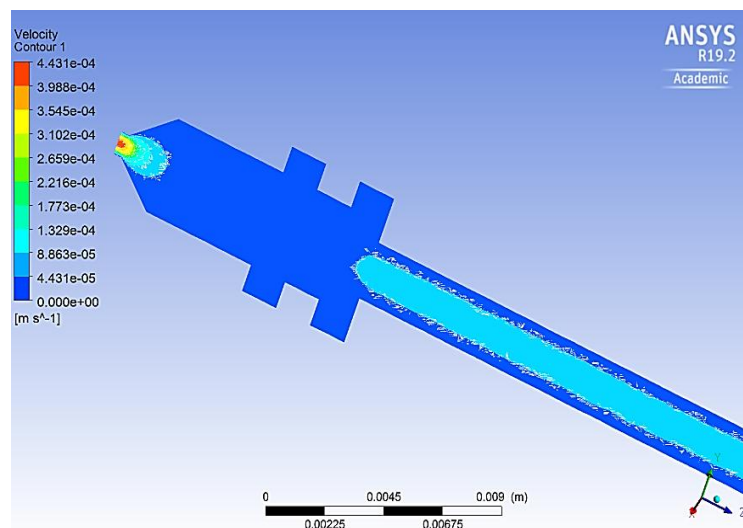


Fig. 2 velocity ditribution along length of circular exit nozzle

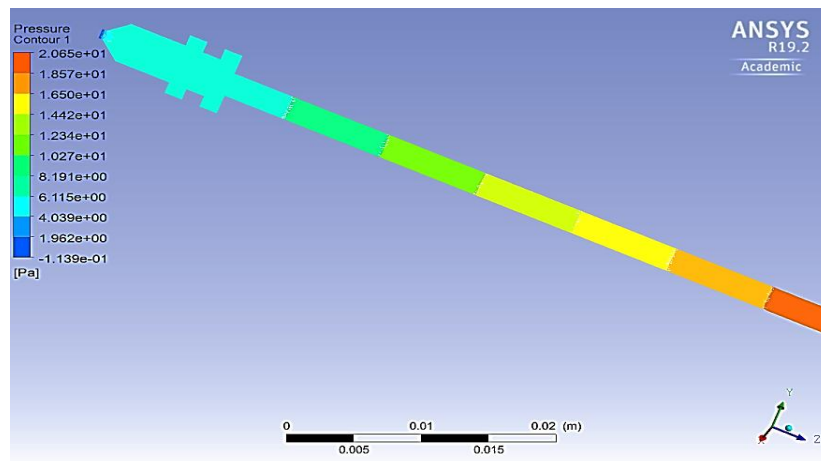


Fig. 3 Pressure distribution along length of circular exit nozzle

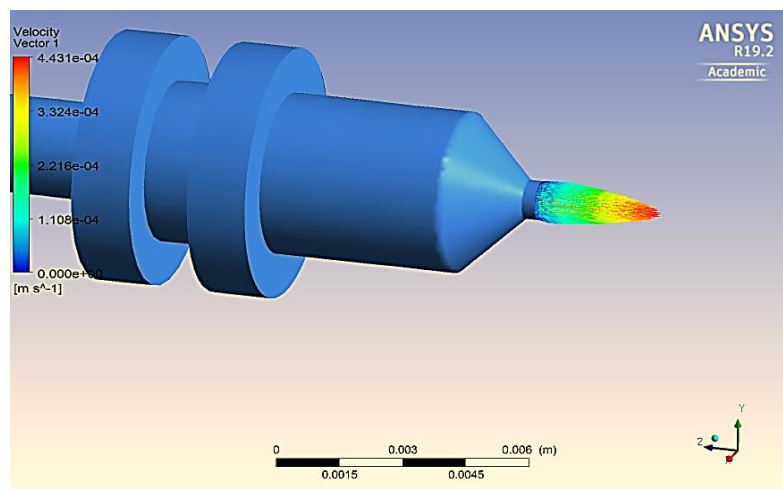


Fig. 4 vector flow out form the circular exit

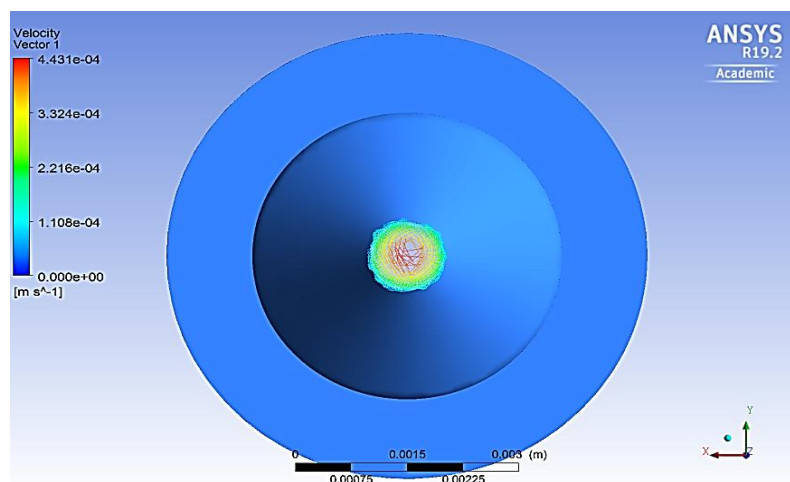


Fig. 5 vector flow Cross section from circular exit

Figure 1 shows that velocity behaviour in all direction at particular iteration of calculation. Also figure 2 shows that velocity distribution along length of nozzle on one reference plane which is parallel to XZ-plane. Also it is observed that maximum value of velocity is obtained at centre part of tip of nozzle which is approximately 0.4431 mm/sec. Figure 3 shows that pressure distribution along length of nozzle with respect to reference plane. For circular exit it is seen that very large variation in pressure along length of nozzle during deposition process. In all this three figures red colour indicating highest values and blue colour indicate lowest value for that particular properties. In that images are taken during analysis in ANSYS Fluent 19.2 Academic. Figure 4 shows flow behaviour and its shape from exit of nozzle and

form that seen that all vectors are came out in form of circular bundle. The material nearer wall of nozzle has low velocity but central material has maximum value of velocity. Now similarly for square shaped nozzle exit analysis done and following results are obtained which are given below.

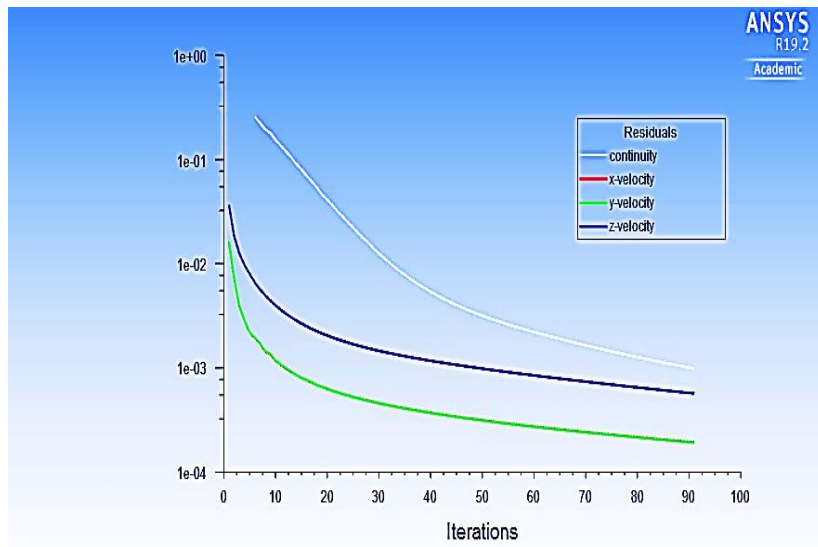


Fig. 6 Velocity behavior for all direction

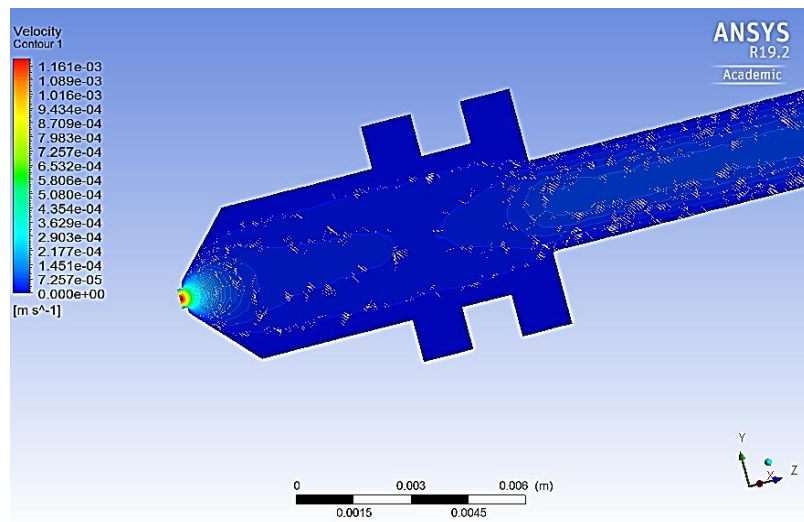


Fig. 7 velocity distribution along length of square exit nozzle

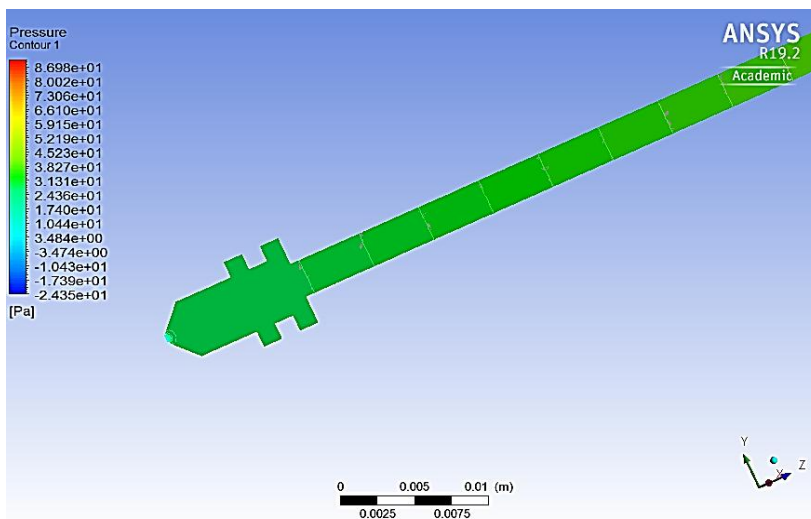


Fig. 8 Pressure distribution along length of square exit nozzle

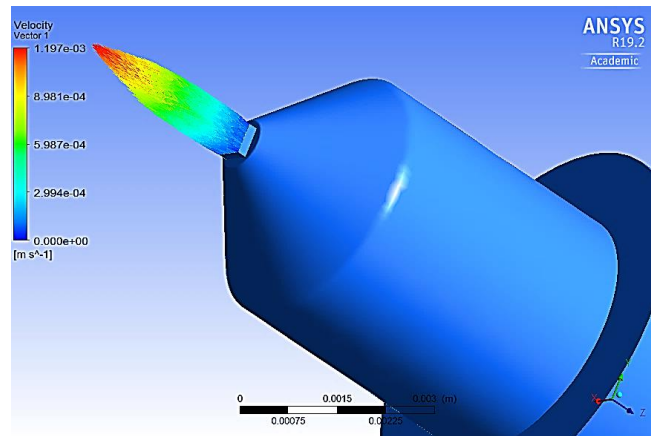


Fig. 9 vector flow out from the square exit

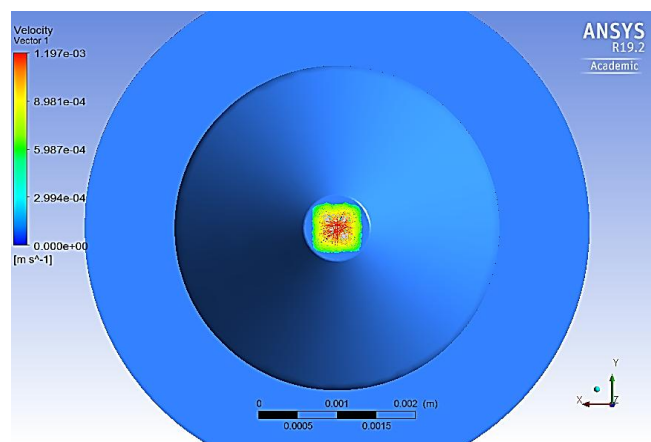


Fig. 10 vector flow Cross section from the square exit

Figure 6 shows that velocity behaviour in all direction at particular iteration of calculation. Also figure 7 shows that velocity distribution along length of nozzle on one reference plane which is parallel to XZ-plane. Also it is observed that maximum value of velocity is obtained at centre part of tip of nozzle which is approximately 1.197 mm/sec. Figure 8 shows that pressure distribution along length of nozzle with respect to reference plane. For square exit it is seen that very approximate uniform distribution of pressure along length of nozzle during deposition process. In all this three figures red colour indicating highest values and blue colour indicate lowest value for that particular properties. In that images are taken during analysis in ANSYS Fluent 19.2 Academic. Figure 9 shows flow behaviour and its shape from exit of nozzle and from that seen that all vectors are came out in form of square bundle. Now similarly for triangular shaped nozzle exit analysis done and following results are obtained which are given below.

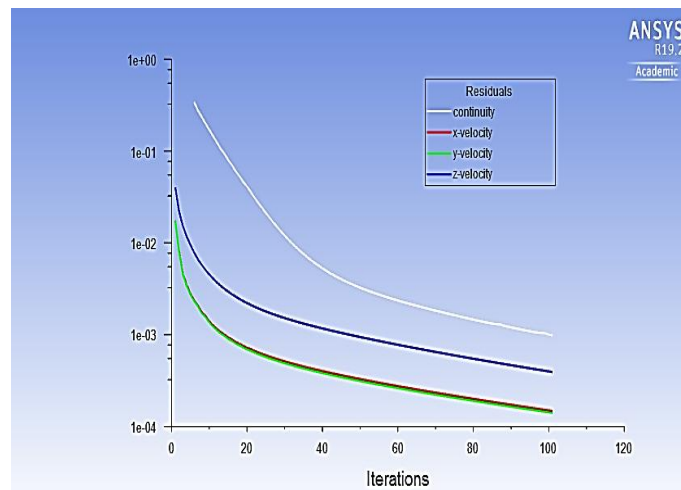


Fig. 11 Velocity behaviour for all direction

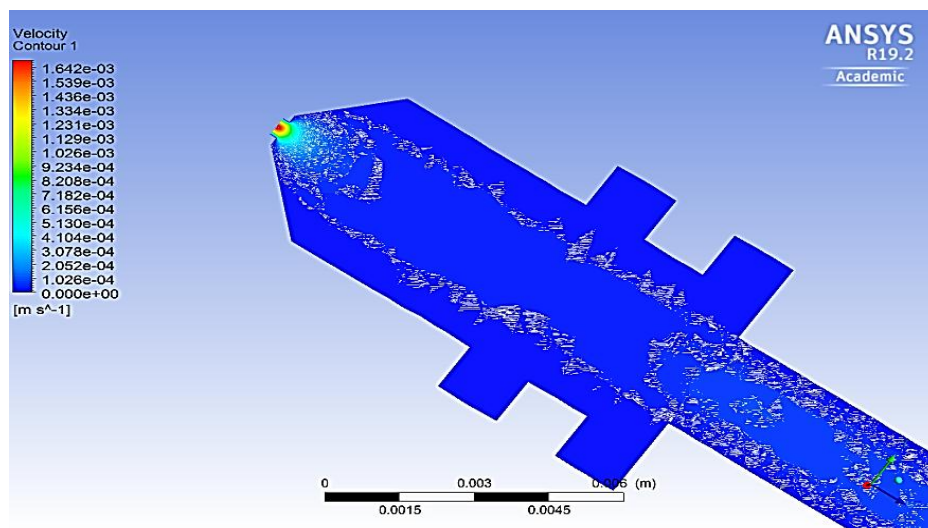


Fig. 12 velocity distribution along length of triangular exit nozzle

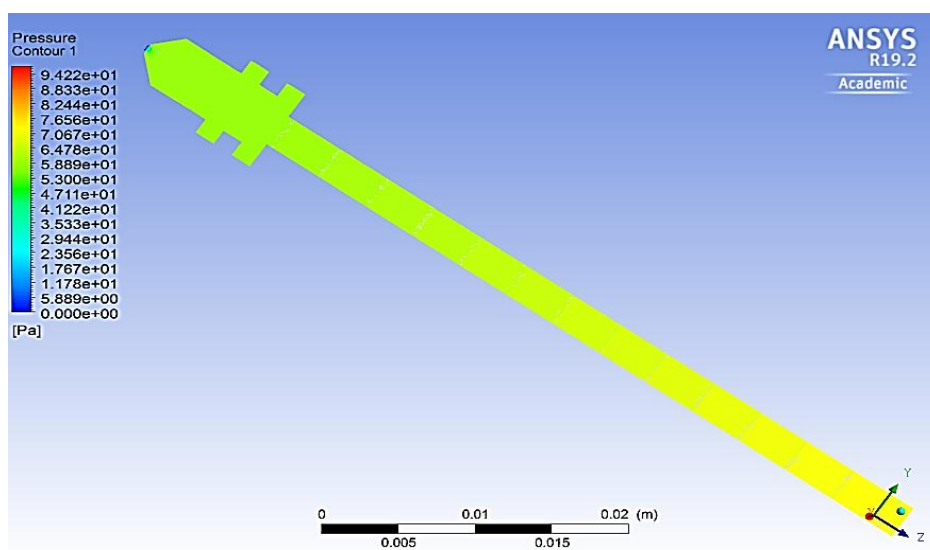


Fig. 13 Pressure distribution along length of triangular exit nozzle

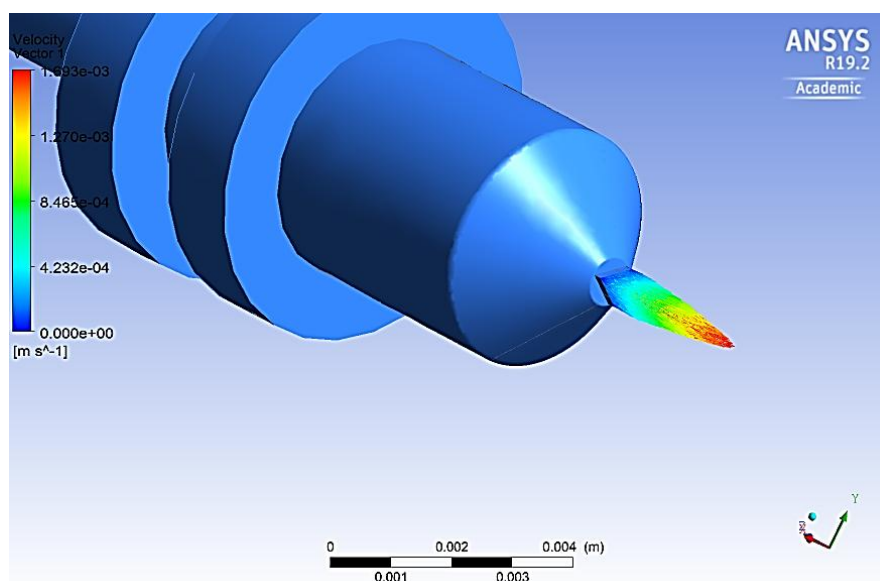


Fig. 14 vector flow out form the triangular exit

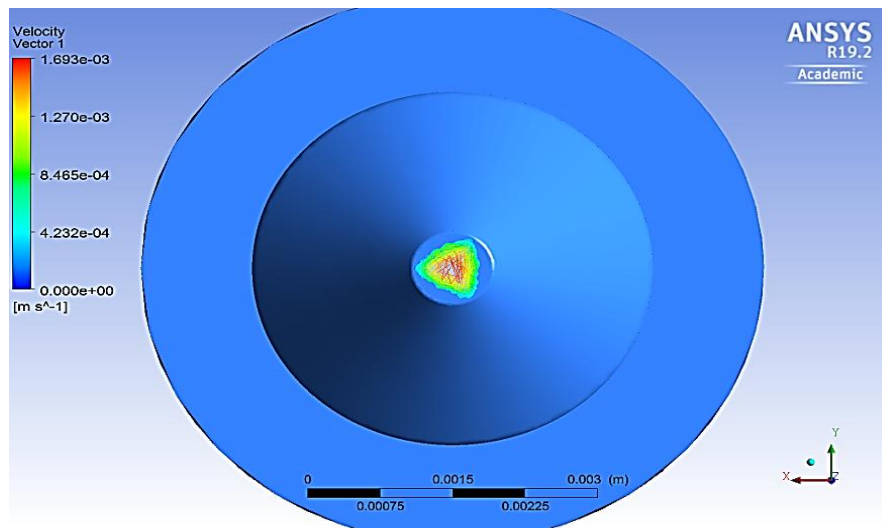


Fig. 15 vector flow Cross section from triangular exit

Figure 11 shows that velocity behaviour in all direction at particular iteration of calculation. Also figure 12 shows that velocity distribution along length of nozzle on one reference plane which is parallel to XZ-plane. Also it is observed that maximum value of velocity is obtained at centre part of tip of nozzle which is approximately 1. 693 mm/sec. Figure 13 shows that pressure distribution along length of nozzle with respect to reference plane. For triangular exit it is seen that some amount of variation in pressure along length of nozzle during deposition process. In all this three figures red colour indicating highest values and blue colour indicate lowest value for that particular properties. Figure 14 shows flow behaviour and its shape from exit of nozzle and form that seen that all vectors are came out in form of triangular bundle. The material nearer wall of nozzle has low velocity but central material has maximum value of velocity.

Bead spreading can be improved by controlling the final contact angle also by reducing inter-bead voids which would ultimately improve the mechanical properties too. The contact angle can be controlled by positively utilizing the Barus effect, the expansion phenomena of any non-Newtonian fluid when it emerges from a nozzle to an open space. When the flow comes out with a certain speed and pressure, the inner pressure of the flow forces the material to expand in the open air, this phenomenon would result the extruded material to swell in environment and come out with some unexpected shape. It is observed in study circular nozzle leads to elliptical cross-sectional beads resulting higher inter-bead void contents. It is to be noted that a square cross-shaped bead geometry would reduce or remove the inter-bead voids in the specimen and improve the mechanical properties. As a result, a nozzle geometry is desirable to achieve an extruded bead with square cross-section. When the molten polymer extrudes out of nozzle it expands along the edge, the longer of the edge the more obvious of this expansion.

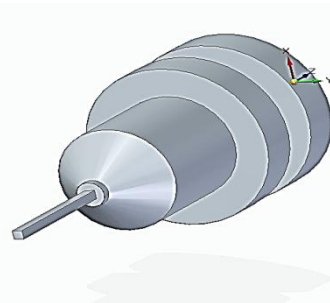


Fig. 16 square shaped filament from square nozzle exit

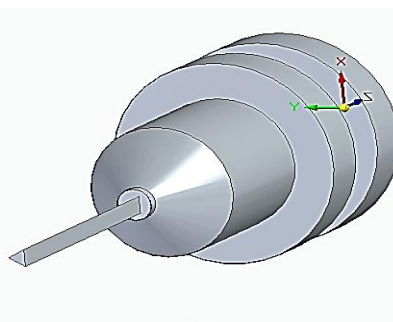


Fig. 17 triangular shaped filament from square nozzle exit

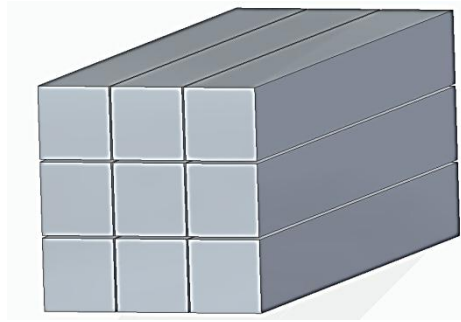


Fig. 18 square filament deposition and bonding

Observing the velocity profile of square-shaped nozzle, this smooth transition is predicted. This would result in the shape of extruded material to be different than that of nozzle. So, simulations of velocity and pressure drop for different nozzle geometries are conducted in this research. The next step would be to examine the swelling phenomena for these nozzle geometries for different nanocomposites and find out a relationship between pressure drop and velocity with horizontal, vertical swell and aspect ratio. By controlling these parameters of extrusion process and nozzle shape, a rectangular shape of extruded filament could be obtained with decreased void contents and increased deposition quality.

V. CONCLUSION

This research paper presents the comparative study of flow behavior, pressure and velocity distribution of material through different nozzle exit geometries like square and triangular this research work done for identifying nozzle shape which give better velocity and uniform flow of molten polymer material during deposition process on platform. From this analysis of all three shapes of nozzle exit geometries, it is seen that minimum value of velocity obtained for circular shape and maximum value for triangular shaped while square shaped nozzle gives intermediate value and their value are 0.444, 1.197, and 1.693 mm / sec respectively. For pressure distribution, it is more uniform for square shape than other shaped nozzle exit. But it is founded that the material flow from square exit shape nozzle, filament generated are gives better bonding strength to filaments and improve mechanical and surface properties. So it is concluded that for better qualities of fused part square shaped nozzle exit is utilized for manufacturing.

VI. ACKNOWLEDGEMENT

I would like to express the deepest appreciation to my guide Prof. A. B. Pandey associate professor at Faculty of technology and Engineering, MSU, Baroda and Prof. Saxena, associate professor at Sardar Vallabhbhai Patel Institute of Technology, Vasad (041). Who have the attitude and the substance of a genius he continually and convincingly conveyed a spirit of adventure in regard to research, and an excitement in regard to learning new things. Without his guidance, invaluable constructive criticism, friendly advice and persistent help, this work would not have been possible. I further would like to whole-heartedly express my gratitude to all my friends, family members for providing me their untiring support in the compilation of this work.

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