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Various Infill Patterns and their Effect in 3D Printable Materials

A Review Report on the Effect of Different Infill Patterns in 3D Printable Materials

Deobrat Akhouri[1], Debanjan Karmakar[1], Dipabrata Banerjee[2*], SwayamBikash Mishra[3]
[1]B. Tech Scholar, Kalinga Institute of Industrial Technology, Bhubaneswar, 751024
[2]PhD Research Scholar, Kalinga Institute of Industrial Technology, Bhubaneswar, 751024
[3]Assistant Professor, Kalinga Institute of Industrial Technology, Bhubaneswar, 751024

Abstract:- This research paper describes about the applications of Infill pattern and optimization on 3D built parts. The infill is generally used in 3D built parts to provide them additional strength. Basically, Infill is a repetitive structure which takes up the empty space inside the 3D built parts. Besides this, it also provides strength to the 3D built parts. Depending upon the percentage of infill used, the parts inside a 3D built parts can be made hollow or 100% solid. The suitable percentage of infill to be used and the influence of raster angle on the infill are also discussed in the paper. Also, the effect of different stresses on the infills will be highlighted in this Paper. The parameters which have a direct impact on the mechanical properties have been considered. The influence of water absorption and extrusion temperature on the PLA is also shown. The ways to improve the mechanical properties of the 3D printed parts for better applications in each and every diverse field is also discussed. The impact on the adhesion strength due to layer thickness and printing orientation is also studied. Depending on the application of the 3D printed part, Different layer thickness and printing orientations can be used, which has been elaborated. The outcome of layer thickness on printing time or manufacturing duration of the 3D printed part is also analyzed.Present Review Report is a conclusive study of different types of Infills, their uses and their advantages.

Keywords:- *Stereolithography; Wanhao Duplicator i3 Machine; Shimadzu UTM; Raster, PLA.*

I. INTRODUCTION

Fused Deposition Modelling is a technique which is widely used now-a-days to manufacture quick 3D models. The designs are mainly made using Computer Aided Design software (CAD). CAD models are generally saved in stereolithography file format (STL). After the design is made, it is divided into number of horizontal layers by slicing software. Assembly of different 3D manufactured parts are done by additive manufacturing. ABS and PLA are the two widely used polymers used for additive manufacturing now a days. To increase the strength of the 3D built parts, plating is done. Moreover, Infills are used in large manufactured parts. Infill is basically a repetitive structure which is used to fill the empty spaces inside the 3D built parts. Infills are mainly in hidden form and provide stability to the 3D built models. It also reduces the weight of the models to a large extent. There can be various types of infill Patterns depending upon the patterns, densities and orientations. Where strength is a major concern, 100% infill is used. The infill percentage is decided by depending upon the need and the use of the 3D built models. On using higher infill density, the mass of the 3D model also increases. When the structure strength is not the primary concern, than 20-30% infills can also be used inside the models. Different types of materials can be used for infills depending upon the use of the model. If strength is the major concern of the 3D built parts than materials like PLA, ABS, PETG, Nylon, etc are to be used. In case of flexible strength Filaflex is used. Filaflex is from the group of TPE (Thermoplastic Elastomers), which is also named as thermoplastic rubber. This is under the class of copolymers or a physical mix of polymers, generally a mixture of plastic and a rubber. It consists of materials with both thermoplastic and elastomeric properties. Another material TPU (Thermoplastic polyurethane), which is a melt-processable thermoplastic elastomer with high durability and flexibility. These are generally used to get the best possible result. At present, there are various choices for extrusion based FDM machines. A few procedure boundaries are accessible for each of these machines. For example, Print direction, layer thickness, raster point, and raster thickness and procedure boundaries might be the key factor in progress of FDM machines when concentrated on mechanical properties. FDM frameworks are very restricted on the basis of shape and size of parts that can be produced. With less support materials and printing large FDM parts, printing in section and bonding them adhesively is considered to be the solution. Multi-material infill can possibly quick advancement and takes into consideration more unpredictable structures, appearances and upgraded mechanical properties. There are various factors that influence the mechanical properties of the FDM parts other than infill percentage. These factors include raster angle, layer thickness, air gap, printing orientation, and cap thickness where the Raster angle is the angle between the raster and loading stress direction. Air Gap is the distance between two filaments of same layer. Layer thickness is the thickness of the layer deposited by the nozzle of the FDM machine and it solely depends on type of nozzle used. The Raster thickness used to print the infill pattern is termed as Cap Thickness. Printing Orientation refers to the inclinations of the 3D printed object with the platform with respect to different axis. The main advantage of 3D printing is that with more resistant, good attachment high number of component can be integrated in a single part.

In practice various infill pattern are already preset in the 3D printing machines, such as Rectilinear, Aligned Rectilinear, Grid, Triangles, Starts, Cubic, Concentric, Honeycomb, 3D Honeycomb, Gyroid, Hilbert Curve, Archimedean Chords, Octagram Spiral, etc. Some are shown in below figure.

Among the various infill patterns, Honeycomb, Grid, Triangles, are best suited for different purposes. The Honeycomb infills are required for stiffer and stronger when compared with rectangular infill. The honeycomb infill is sometimes known as Hexagonal infill pattern. It provides better tensile strength. It is also said that the hexagonal or honeycomb infill is most suited, if we look for a good balance of material saving, time saving, energy saving, speed and require higher strength. The grid infill pattern has the advantage about the print speed and it is the complex one if compared with triangle infill. Somewhere the triangular infill is the strongest infill pattern because; the triangles are in the strongest shape. Parts printed with triangular infill are not likely to deform easily and provide the best support behind the walls of the part. Rectangular infill is the only infill type which can achieve a 100% density part, because it consists of a grid of parallel and perpendicular extrusions. The gyroid infill has the benefit that we can print with a lower infill percentage and still able to get a good result.

The nozzle temperature and the nozzle travelling speed plays a significant role in deciding the quality of the 3D printed material. It is recommended to have a nozzle speed of 110m/s if the part is built from the economic point of view whereas to built a high quality part, the nozzle travelling speed of 155 m/s is utilized.The nozzle temperature of 240 ^{0}C is required to derive a 3D printed part of high strength, but if the nozzle temperature gets more than 240 ^{0}C then it may result in the polymer degradation of the part.

Now a days, composite materials are being used in 3D printing due to the scarcity of existing materials.Thermoplastic polymeric material is significantly being used for fused deposition modelling but the strength may not be sufficient for applications which require high performance, so nano- particles and short fibers can be utilized to improve the nature of printing filaments. ABS reinforced with carbon fibre is found to have better mechanical properties as compared to pure ABS and on the other hand the PLA reinforced with carbon fibre Is also found to have better tensile strength and reflects better mechanical properties as compared to the pure PLA.

As discussed earlier, the infill patterns have different density as per the required stiffness and strength of the printed part for the use purpose. It varies from part to part from 0% to 100%. The following figure shows the Honeycomb or Hexagon infill pattern with various percent of infill.

Initially, a 3D solid model is made using CAD software. Then it is converted into stereolithography format. Then it is sliced horizontally using slicing software in a number of layers. The samples of FDM are made using a Wanhao Duplicator i3 machine. ABS is used for specimen preparation. Uniaxial tensile tests were carried out in universal testing machine to find out the mechanical properties of the 3D built parts. Printing parameters and test specimen parameters are listed below.

A complete relationship between Infill rate, raster orientation, Infill pattern, Young's modulus is carried out. There was an increase in the tensile strength from 0-90° wiggle pattern. It was observed that the strength of the specimen increases in infill rates between 16.1Mpa at 20% to 28.9Mpa at 100%. PCL (Polycaprolactone) was also used to make 3D scaffold. Compression tests and Scanning electron microscope was used to magnify them. It was shown in the results that by increasing the pressure of extrusion with fixed percentage of infill density, it results in less accurate printing. It was also observed that by using ABSplus-P430 and a T14 nozzle tip with D1(low), D2(high), D3 (double dense) and D4 (solid) as infill patterns , D3 had the longest printing time whereas D2 require the maximum amount of materials. Tensile test was conducted with Universal tensile testing machine and it was observed that tensile strength measured was 13 times of each PLA specimen. It was concluded from the results that the main tensile strength increases as the internal filling density increases. The tensile elongation is also increased at the breakpoint but gradually decreased at 100%density. Flexural strength was found out by using Shimadzu Universal testing machine. It was concluded that strongest tensile properties were observed while he infills are printed with the rectilinear infill pattern. Meanwhile, honeycomb patterns attains higher stain due to fabrication of the printed parts where due to the extrusion of excess materials from nozzle, causing the decrease in the elongation of the infill pattern along with the orientation is the molecule chain.

The tribo pairs is known to accounts for 25% of total energy consumption out of which 20% accounts for overcoming friction. Therefore, this technology can be used to minimize the energy consumption and Co2 emissions and the cost which is the utmost important thing. In the recent days the polymeric materials are replacing the metallic material due to their high strength and light weight. Though, there is an insignificant difference between ABS and PLA printed parts and in their mechanical properties.

The tensile test was carried on ABS and PLA tests as per the ASTM standards. It was observed that PLA specimen are known to exhibit better mechanical properties and are mostly used due to their light weight and therefore mostly used in the manufacturing of tribo-pairs and have better coefficient of friction.

The stresses in the filaments will be different on the basis of angle of the filaments relative to the direction of the force applied. Sometimes the filaments are in a pure tensile stress state (0º), and in different cases they are in a blend of tensile stress and shear stress (- 45º and +45º). It was observed that the 0º/90º orientation was harder to misshape from its unique state, contrasted with the - 45º/+45º orientation. Therefore, the 0º/90º Raster angle gives a stiffer structure. Whereas it was observed that at -45º/+45º Raster Angle there was high elongation at breaking point and high toughness. The layer thickness, print orientation and raster angle assumes a vital job in giving better mechanical properties. The more prominent layer thickness increases mechanical properties whenever printed in the X and Z directions, and lower layer thickness is just perfect for Y direction. Cap thickness and air gap of the infill likewise assumes a crucial job in changing the mechanical properties of the object. The cap thickness is known to be the boundary that decides the flexural strength and the air gap expands the weight and modulus to weight ratios, this makes the Cap thickness a much important factor. Wall thickness was not found to modify the strength of the item. It was also observed that the Layer thickness and water absorption additionally change the mechanical properties of the specimen. Lower layer thickness gives better adhesion between layers along these lines expanding the tensile strength while the nominal increase in water absorption in the polymeric material gives a spike to the adhesion between the layers consequently expanding the toughness and strength. It was further concluded that the infill density might be expanded to 100% or a few kinds of defensive covering can be used. Increasing the infill density gives better outcomes.

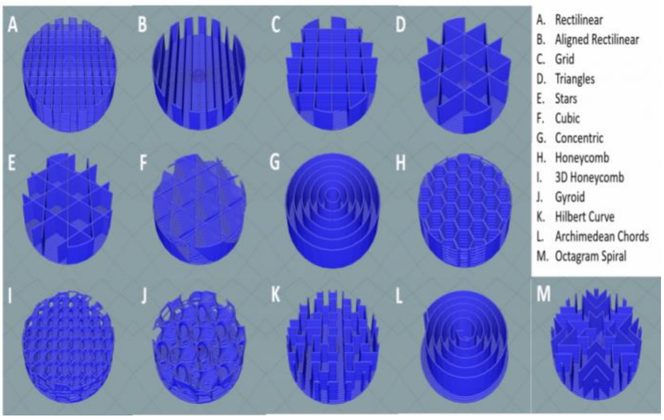

Fig1: Various Infill Patterns used in 3D Printing Machines

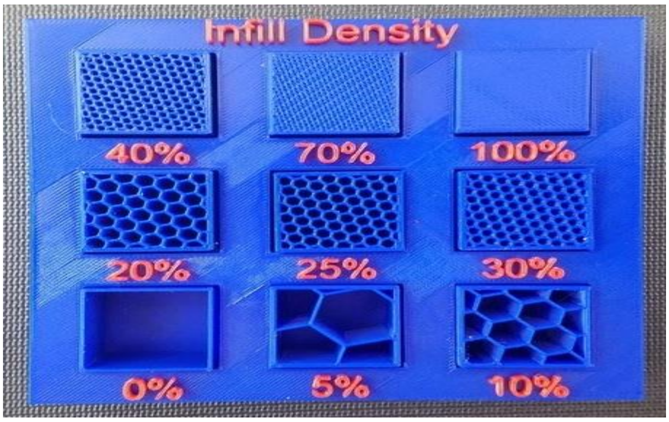

Fig2: Various Infill Density of Infills used in 3D Printing

II. PROCESS DETAILS:

Table 1. Printing Parameters

Print parameters	**Value**
Layer height	0.2mm
Infill percentage	20-100%
Infill orientation	0-30-45-90^0
No of infill layers	12
Total no of layers	20

Table 2. Test specimen Parameters

Parameter	**Value**
Nozzle diameter	0.75mm
Primary layerheight	0.2mm
Printing speed	30mm/s
Nozzle temperature	250^0
Bed temperature	100^0

Table 3. Difference between properties of PLA and ABS Built parts

Properties	**ABS**	**PLA**
Tensile Strength	24 Mpa	35 Mpa
Elongation	4.5-45%	7%
Flexural Modulus	3.1-8.4 Gpa	5 Gpa
Density	1.0-1.6 g/cm^3	1.5 g/cm^3
Melting Point	amorphous	175^{0}C
Biodegradable	No	Yes

- For testing ABS P400 tensile, flexural and impact testing techniques were used by and various printing factors like layer thickness, raster angle,printing orientation, raster width and air gaps were taken into consideration and were analyzed by Sood et al in 2010 and all of these parameters were found to effect the strength of the sample and it was also found that porosity between the printed layers can also weaken the structures.
- For material abs Plus P430 ,techniques like tensile flexural, impact and hardness tests were carried out by Nunez et Al in 2015 and on performing these tests it was found that parameters like layer thickness and infill density have the tendency to alter performance and dimensional accuracy of the 3D printed sample.
- For material ABS Plus P430 , testing techniques like tensile, flexural and compression were considered by Baich et al in 2015 and it was observed that considerable infill density not only provides high strength but also can affect the production cost and economy.
- For PLA materials, testing techniques like tensile test were performed by Harpool in 2016 and it was found that out of all the patterns hexagonal portrayed the highest strength.
- On PLA materials, testing techniques like tensile test were performed by Alafaghani in 2017l and it was also concluded that alteration of parameters can directly affect the mechanical properties of the 3D printed part.

- On ABS materials, testing techniques like tensile test was carried out by Dudescu in 2017 and it was observed that optimization of printing parameter can help to derive high quality parts.
- On ABS materials, testing techniques like Taguchi method of array 127 was carried out by Rahman et al in 2018 and it was observed that a high precision in the CAD model and by correctly fixing different printing parameters,high dimensionally precise parts can be derived.
- For material ABS Plus P430 , techniques like tensile test were considered by Panda et al in 2018 and it was concluded that changing of different process parameters can directly influence the mechanical properties.
- On PLA materials ,testing techniques like tensile and rheological tests were performed by Behzadnasab and Yousefi in 2016 and it was concluded that a set nozzle temperature has a direct impact on the quality of printed parts.
- On PLA ,ABS and PET materials ,testing techniques like tensile tests were performed by Johansson in 2016 and it was concluded that a high strength is achievable if there is a good bonding between the layers of the 3D printed part.
- On HIPS materials ,techniques like Cross sectional photography were performed by Kaveh et al in 2015 and it was concluded that factors like raster width ,nozzle temperature and flow rate can impact the quality and mechanical properties of the specimen.
- On PVA materials ,techniques like photography, fluorescence concentration and dissolution were considered by Goyanes et al in 2014 and it was observed that nozzle temperature can influence the gap between the layers and quality of the printed specimen.
- On PLA composite and PP composite materials,techniques like tensile test and SEM were performed by Okasman et al in 2003 and it was concluded that high strength in composite parts can be achieved by utilizing good interfacial adhesion between the matrix and reinforcement.
- On ABS and carbon fibre powder materials,techniques like tensile,flexural and SEM tests were performed by Ning et al in 2015 and it was observed that ABS reinforced with fibres were having better mechanical properties as compared to pure ABS.
- For PLA and carbon fibre bundle materials, techniques like tensile,flexural,DMA and SEM tests were considered by Li et al in 2016 and it was concluded that continuous fibres can portray high strength and mechanical properties than short fibres and better adhesion was also observed between the fibres and matrix in case of modified fibres.
- For PLA and carbon fibre bundle materials, techniques like flexural and SEM tests were considered by Tian et al in 2016 and it was observed that we can achieve high flexural strength in composite parts by increasing the volume fraction of composite parts.
- For PLA and chopped carbon fibre,techniques like tensile and SEM test were performed by Ferreira et al in 2017 and it was concluded that if short fibres are aligned along the printing direction,then it may increase the strength and stiffness in the printed specimen.

III. CONCLUSION

Infill is used in 3D build parts to improve their strength and structure. Various infill patterns are used depending upon the need. Honeycomb pattern is the best suited, if strength is the basic requirement. With varying infill percentage and raster angles, infills can be used in a variety of ways. The materials used in infills are PLA,ABS and Nylon. Uniaxial tensile tests and fatigue tests were carried out to find the strength of the 3D built parts. It was also observed that from 0-90° wiggle pattern, the strength increases abruptly. The mechanical properties of ABS built parts are influenced by printed patterns as well as orientations. It was also concluded that the E-modulus increases with infill percentage. It was also concluded that for PCL scaffold, 80%infill density and 60psi pressure gives the maximum accuracy while printing. It was also concluded that any settings change in ReRap 3D Printer can affect the printing quality of the specimen and can give deviations in the findings. Factors such as raster angle, layer thickness, printing orientation, cap thickness can also alter the mechanical properties in various ways. Layer thickness intensifies mechanical properties of the mechanical part when printed in X and Z direction and a lower thickness is observed when it is printed in Y direction.The raster angle with 0º/90º was more difficult to deform compared to the part with raster angle -45º/+45º but high elongation at break and toughness was observed at raster angle -45º/+45º. Cap thickness is one of the most important factors used to determine or modify the flexural strength, whereas the air gap was found to alter the modulus to weight ratios but wall thickness was not found to alter the strength of the part. It was also found that better adhesion was a result caused by the lower layer thickness and the increase in water absorption the PLA can increase the adhesion between the layers thus increasing the strength of the part.

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