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Effect of Fill Angle on Adhesion Strength of 3D Print on Cotton Fabric in Shear Mode

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ABSTRACT

Wearable cloths undergo a lot of shear stretching. It is important to study the role of printing parameters which may improve adhesion capacity between printed thermoplastic material and the cotton fabric. In this paper, effort has been made to determine the best set of printing parameters for effective FDM based printing on cotton fabrics using 3D printer. Printed samples are tested in shear mode of loading to evaluate adhesion capacity of thermoplastic printing material on cotton fabrics. Cotton fabric with rectilinear infill pattern has been selected for investigating in shear mode condition. Using an infill percentage of 80 per cent gives best adhesion strength. This study may further be used for printing smart material on fabric substrate.

Keywords: *Fused deposition modelling; Adhesion capacity; Fill angle; Z-offset distance.*

1.0 Introduction

Additive manufacturing is a fast-emerging technology for solving problems associated with conventional manufacturing processes. The term ‘additive’ in Additive Manufacturing (AM) means gradually adding material until the final geometry is obtained. Conventional manufacturing techniques are ‘subtractive’ in nature in which material is gradually removed from the work piece till the final geometry is obtained. AM is a three-step method involving design, fabrication and finally installation of the product at its requisite location. Conventional methods have a number of steps even before the beginning of actual fabrication. Rapid prototyping or 3D printing is one of the major applications of AM which directly fabricate 3D objects from CAD design. Rapid Prototyping (or 3D printing) is used in different areas such as medical for fabricating customized medical implants, in aerospace for complex design structures etc. 3D printing techniques are broadly classified on the basis of phase of materials such as powder, liquid or solid filaments which are used as feed for fabricating 3D models.

2.0 3-D Printing on Fabrics

3D printing of textiles is broadly classified as fully 3D printed textile or direct 3D printing on textiles or fabrics. Presently indirect type of 3D printing on fabric material is popular where 3D print on the objects is done separately and after fabrication, it is made to stick on fabric by means of adhesives. This is seen in fashion industry very frequently where focus is on increasing the aesthetic value of fabrics. FDM based 3D printing has been carried out in many previous works. 3D printing of various polymeric materials has taken place on different fabric materials in which Poly Lactic Acid (PLA) gave the best results. Woven fabrics have

much better characteristics with polymers due to its fibrous surfaces [1]. 3D model by using flexible filament material such as Soft PLA and TPU have also been used on different fabric materials. Quality of fabric substrate, its thickness and surface roughness play crucial role in good adhesion characteristics [2]. Effects of 3D printing parameters were investigated in a number of previous studies. Nozzle temperature and bed temperature have a significant role in improving adhesion characteristics [3]. Earlier works were more focused on varying printer setting which includes temperature controls of components like extruder nozzle, bed temperature etc. whereas the present study investigates the effect of varying print settings, specifically fill angle on the adhesion characteristic in shear mode of loading condition. It experimentally evaluates the bonding

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strength in between the fabric and polymer using tensile testing method.

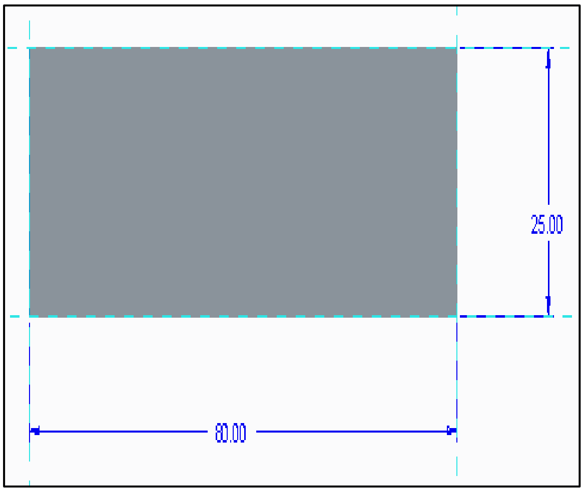
3.0 Materials and Methods

Thermoplastic material used for 3D printing - PLA filaments of diameter 1.75 mm are procured from 3DTechx. Fabric material on which samples are printed is cotton weave fabric. CAD modeling CREO 2.0 software is used for evaluation.

3.1 CAD modeling

CAD model of rectangular shapes of dimension 80 mm x 25 mm x 0.6 mm is designed by using CREO 2.0. The design file is saved in STL format which is compatible with slicing software package. Slicer 3r software is used for slicing the 3D model and generates G-codes for it. Printing parameters values are entered prior to slicing of the 3D model.

Figure 1: 2D Design of Sample



3.2 Printing parameters

Printing parameters are those set of variables which play crucial role in defining the overall quality of 3D printed products. Printing parameter includes bed temperature, extruder nozzle temperature, infill density etc. In case of 3D printing on fabric material, z-offset distance which is the distance between nozzle and printing bed need to be addressed well for preventing the nozzle struck into fabric while printing. Hence, with fabric some extra clearance is given between the nozzle and fabric. Nozzle temperature range for PLA filament lies in the range of 190 ºC to 230 ºC. Fill angle is the angle with respect to y-axis at which material deposit on the printing bed. 45% infill percentage is the default infill percentage of any slicing software. Available literatures suggest the use of high nozzle temperature for better result as compared to using normal value. The values of all the parameters selected prior to 3D printing are presented in Table 1.

Table 1: Printing Parameters

Parameters	Description
Nozzle diameter	0.20 mm
Infill	45%
Material used	PLA (1.75 mm White)
Print speed	22.5 mm/s
Nozzle temperature	230°C
Bed temperature	60 °C
Layer size	0.20 mm
First layer height	0.30 mm
Z-offset (Cotton)	1.20 mm
Fill Angles	0º, 15 º, 30 º, 45º, 60º, 75º and 90º

3.3 Sample preparation

Figure 1: Fabric Placement

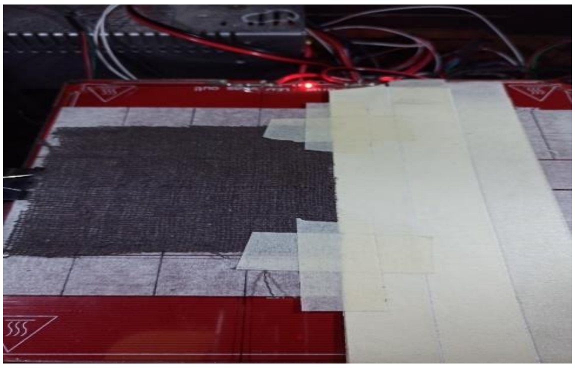
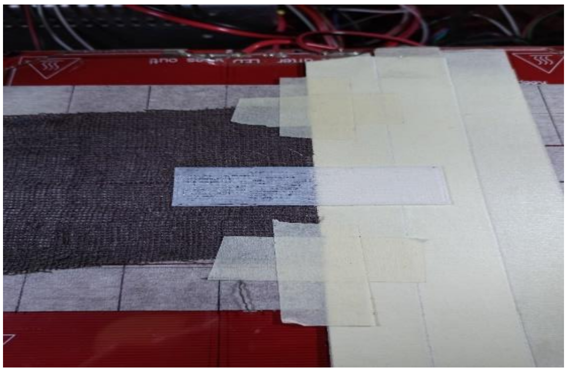


Figure 2: 3D Printing of sample

For sample preparation, fabric material is placed in such a way that while printing half the portion lies on fabric and other half on the thick tape placed over the printing bed as shown in Fig 2.

Figure 3: 3D Printed Sample on Cotton Fabric



4.0 Experimental Investigation

Tensile load has been applied on the sample for evaluating the adhesion capacity using INSTRON 3366.

Figure 4: Testing of Samples

Figure 5: Sample Failure

Prior to testing, parameters like sample dimension, gauge length, separation rate, mode of testing etc. are entered in the Bluehill software used with UTM. Rate of separation is 50 mm / min. Each end of the sample is fixed inside the jaws of UTM and the load is gradually applied till the separation is initiated between the printed sample and the fabric material as shown in Figure 5.

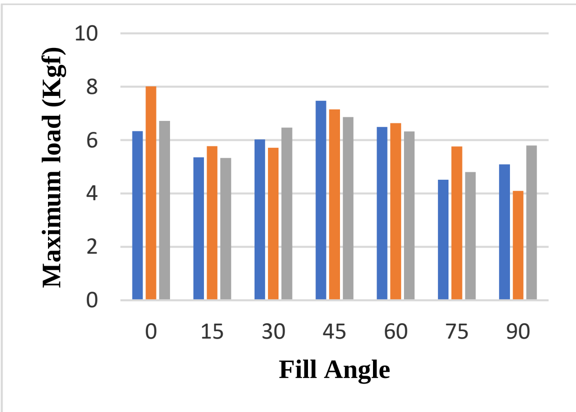
5.0 Results and Discussion

Shear mode investigation of 3D printed sample is performed to evaluate the overall quality of 3D printed model on fabric because wearable cloths undergo a lot of stretching in transverse direction as compared to the normal direction. Therefore, it is important to study the role of printing parameters which play crucial role in improving adhesive strength in between the printed thermoplastic and the fabric.Three samples each of different infill percentage combination are fabricated and tested on INSTRON for finding the maximum load bearing capacity. Separation rate is 50 mm / min while testing the samples. Average of peak values has been calculated for obtaining the final results.

Table 2: Maximum Load Sustained at Different Fill Angle

Fill Angle	Maximum load (Kgf)		
0	6.34	8.01	6.72
15	5.35	5.77	5.33
30	6.02	5.71	6.47
45	7.48	7.15	6.87
60	6.49	6.64	6.33
75	4.52	5.76	4.81
90	5.09	4.1	5.8

Figure 6: Variation of Maximum Load with Fill Angle



6.0 Conclusions

Following conclusions are derived from the investigation:

- 0º fill angle gives best result in terms of adhesion strength between printing material and the fabric.
- At 0º fill angle the direction of deposited material and direction of loading coincide which contributes to high adhesion strength.
- At 0º fill angle the amount of material deposited in the very first layer will be more than any other fill angle which results in better adhesion characteristics.
- Adhesion strength decreases gradually with increase in fill angle..
- Quality of printed sample degrades gradually with time leading to reduce in bonding strength.

This study may be helpful in selecting appropriate set of 3D printing parameters while printing on fabric materials like cotton. Study may be performed on other fabrics. Right set of parameters are crucial as they may reduce the printing time, cost and the material.

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