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3D PRINTING OF PLA ONTO TEXTILE FABRICS

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Abstract: *3D printing is an additive manufacturing technique that produces three dimensional objects through a layering process. Due to its ability to print complex structures, 3D printing has been applied in many disciplines including textiles. Different textiles structures have been printed using 3D printing techniques. 3D printed polymers have also been combined with textile structures to create composites and also enhance mechanical properties. The challenge with those composites has been the adherence of the 3D printed polymer to the textile substrate. Research has been done to improve the adhesion properties by varying 3D printed polymers, modifying fabric properties and also varying the fabric to polymer combinations. In this study a Polylactic Acid (PLA) model was printed on 8 fabric samples that differed in fabric weight, warp density, weft density, warp linear density and weft linear density. The samples were printed using the Athena 3D printer that uses the Fused Deposition Modelling (FDM) technique. The adhesion strength of the polymer to the fabric was then tested according to DIN53530 standard. The results were analysed based on the different elements of the fabric structure. Results showed that while some elements had a great effect on adhesion, others showed no direct effect on adhesion force.*

Key words: *3D Printing, Adhesion, Polylactic Acid (PLA), FDM process, textile fabric*

1. INTRODUCTION

3D printing technique is an additive production method that prints 3-dimensional products. The technique has been applied in many disciplines because of its flexibility and the possibility to print complex designs. 3D printing has been used in textiles to produce knit-like structures, woven structures, lace structures and multi-material products [1][2][3]. 3D printed polymers have also been combined with textile fibres, yarns and fabrics to create composites and also to enhance mechanical properties [4][5][6][7][8]. Although this has increased possibilities for new applications of textiles, there have been challenges in the adherence of the 3D printed polymer to the textile substrate. Adhesion is an important factor as it affects the end uses, durability and the quality of the product. There are different mechanisms for polymer to substrate adhesion, that is, molecular bonding, mechanical interlocking and thermodynamic adhesion [9]. To be able to achieve the best adhesion it is important to modify the parameters and factors that affect the adhesion mechanisms. Brinks et al [10] highlighted the importance of the polymer penetrating into the fabric for better adhesion and they reported that adhesion can be controlled by varying several factors which include polymer viscosity and pressure [10]. Other researchers [11][12] [4][13] have varied fabric and polymer combinations and also experimented with some pretreatments methods such as washing and plasma treatments of the fabric substrates. The structure of the fabric can affect the mechanical interlocking of the polymer to the fabric and hence affect the adhesion. Researchers have hypothesized that mechanical interlocking results in higher adhesion strength and that roughening of the surface provides higher adhesion [9]. Recent studies have shown that the weave pattern and weft density influence adhesion of the polymer to the textile substrate [14]. This study aimed at keeping the printing polymer constant while varying the fabric structures to be able to study the structural properties of fabric that affect adhesion.

Fig. 1: *Fabric Samples for Adhesion Tests*

The samples differed in weave pattern, weight (grams per square meter), warp density (ends per inch) and weft density (picks per inch), warp count and weft count as shown in Table 1.

Table 1: *Fabric sample properties*

Sample Number	**Fabric Weight (Gsm)**	**Warp Density (Ends/inch)**	**Weft Density (Picks/inch)**	**Warp Count (Tex)**	**Weft Count (Tex)**
1	210	52	46	17	73
2	218	282	81	10	50
3	228	69	28	19	59
4	126	68	48	26	31
5	146	68	60	28	32
6	247	75	54	20	72
7	138	64	50	30	33
8	129	25	22	71	76

The 3D printing was performed using the low-cost Athena Fused deposition modelling 3D printer with a 0.4mm nozzle. A rectangle was created using the Solid Works software and converted to a standard tessellation language (stl) file for slicing using the Cura Software. The Cura software sliced the model into the different layers for printing and converted it into a G-Code. The dimensions of the printed rectangles were 150mm x 25mm. The thickness of the rectangles was 0.4mm. Printing was done at an extrusion temperature of 200°C, a printing speed of 50mm/s, a fill density of 65% and a layer height of 0.15mm. Adhesion tests were then carried out on the fabric according to standard DIN 53530 using a Universal Tensile Tester.

3. RESULTS AND DISCUSSION

The variation of the adhesion force of the printed PLA polymer on the selected fabric samples with changes of fabric weight (grams per square meter) is given in fig. 2. The different fabric samples showed different adhesion strengths as shown in the fig. 2. The fabric weight is directly proportional to the warp and weft linear density and the ends/inch and weft per inch. Therefore the results of the aforementioned factors discussed in the following sections may shed some light as to how fabric construction factors affect adhesion force.

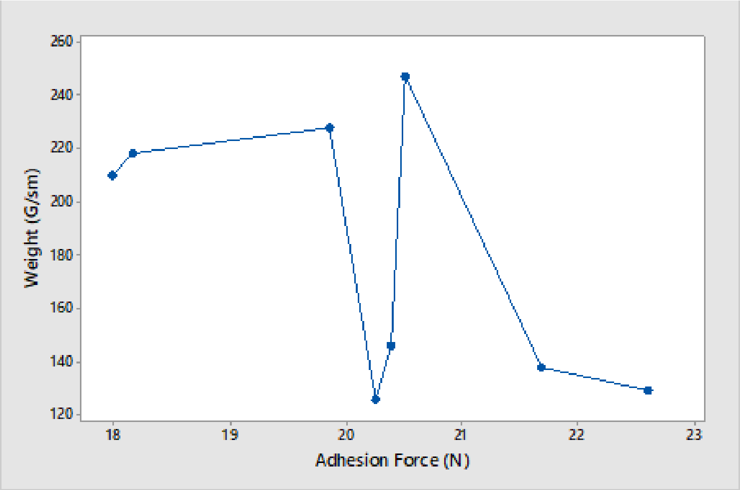

Fig. 2: *Dependence of adhesion on fabric weight*

Fig. 3 shows the relationship between polymer adhesion force and warp density. While the relationship is not direct, there is however a general tendency for the adhesion force to increases the warp density decreases. This can be explained by the fact that as the warp yarns become more densely packed it becomes difficult for the polymer to surround the individual yarns. This leads to less area available for the polymer to hold on to the fabric hence reducing the adhesion force.

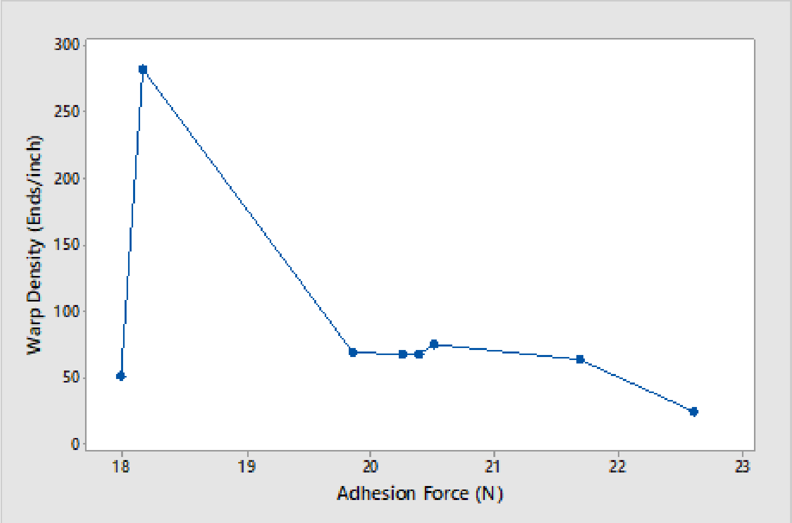

Fig. 3: *Dependence of adhesion on warp density*

The relationship between polymer adhesion force and weft density is shown in Fig. 4, which also shows a general decrease in adhesion force with an increase in weft density. This may be due to the same reasons as discussed for the warp density.

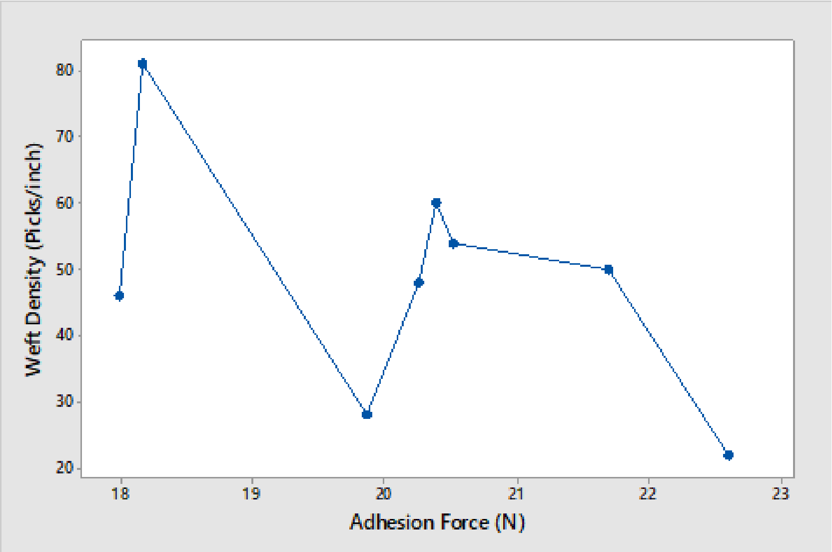

Fig. 3*: Dependence of adhesion on weft density*

In Fig. 5 the relationship between the warp linear density and the polymer adhesion force onto the fabric samples is given, which indicates that linear density is directly proportional to adhesion force. While it may appear that an increase of the linear density provides more area for the polymer to hold onto the fabric, the results of the relationship between the adhesion force and the weft linear density, as shown in Fig. 6, tends to suggest otherwise.

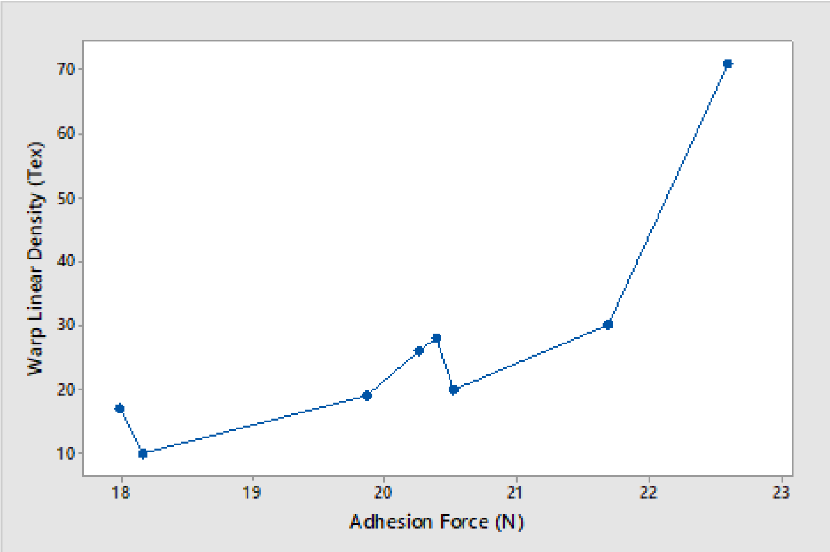

Fig. 4*: Dependence of adhesion on warp linear density*

As exhibited in Fig. 6, the adhesion force did not indicate an easily discernable relationship between the polymer adhesion force and weft density. This calls for more research, especially when there seems to be a direct relationship between the polymer adhesion force and the warp linear density (seen fig. 5).

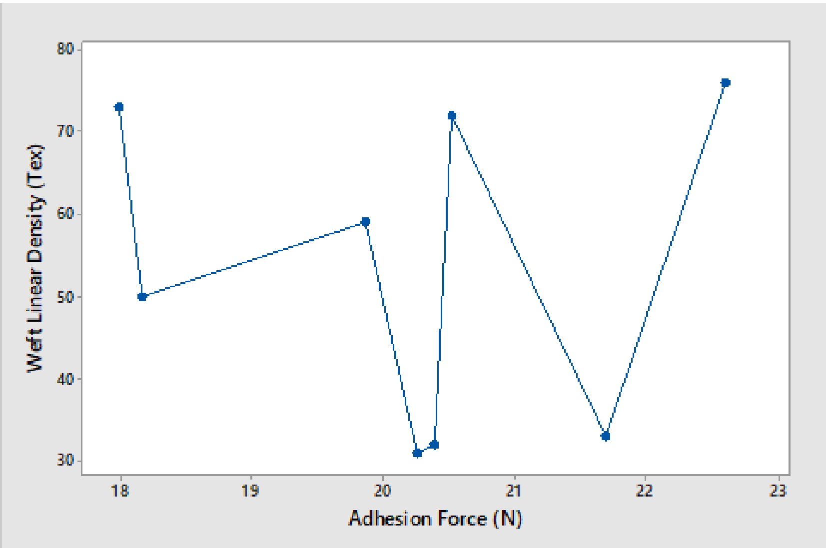

Fig. 5*: Dependence of adhesion on weft linear density*

4. CONCLUSIONS

The aim of this paper was to determine the effect of selected fabric properties on then polymer adhesion onto the fabric. PLA was printed on a variety of fabric samples that differed in weight, warp and weft density as well warp and weft linear density. The samples were tested for adhesion force and the results showed that while warp density, weft density and warp linear density showed an effect on adhesion; fabric weight and weft linear density had no direct effect on adhesion. These tests gave us preliminary results on the adhesion of polymers to fabrics. Future tests can focus on studying the effects of weave pattern and fibre content on adhesion properties.

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