# Comparative Study on the Adhesion Strength of 3D-printed Flex Polymers on Natural and Synthetic Textiles Substrates

Tin Chun Cheung and Sun Young Choi, The Hong Kong Polytechnic University

## Introduction

In recent years, additive manufacturing (AM) has been extensively studied in the fashion & textiles fields with hopes to replace traditional fabrication methods. However, studies have not advanced beyond prototypes due to the mechanical behavioral limitations of 3DP materials. Practitioners have struggled to mimic the behaviors of conventional fabrics. Common techniques include chain mailing (3DP assembled parts), knit/woven/lace/sequin imitations, and multi-material printing (different polymer types). Furthermore, due to challenges in scalability, AM textiles have had limited commercial value in the fashion industry. However, recent expansions into flex filaments (TPU/TPE) have sparked a newfound interest in developing polymer-textile composites. Flex polymers are preferred based on their elasticity and flexibility, well-suited for wearable applications requiring high mobility levels. Such materials have immense potential because they possess the merits of conventional fabrics with the possibility to embed additional functions. To further advance this research area, there is an incessant need to examine and compare the differences in adhesion strength between natural versus synthetic textile substrates with flex polymers.

## Literature Review

*Customizable polymer-textile composites for fashion & textiles*

Recent research has demonstrated the potential of polymer-textile composites (PTC) for application in sportswear, undergarments, assistive garments, and soft wearable robotics. Such research areas are promising due to 3DP being a technology that can be used to create highly customizable textiles. With 3DP, practitioners can embed additional functions (i.e., smart sensors) into fabrics which are challenging with traditional knitting and weaving processes (Kabir et al., 2020). In addition, there are possibilities to enhance the mechanical properties of conventional fabrics and customize aesthetic surfaces through 3DP (Lussenburg et al., 2014; Spahiu et al., 2020).

*Effects of polymers, textiles substrate, and 3DP parameters on adhesion in FPTC*

In PTC studies, practitioners have studied 3DP parameters that affect adhesion strength through studying temperature/print speed (Gorlachova & Mahltig, 2021), pre-treatments (Kozior et al., 2018) and polymer types (Loh et al., 2021). Polylactic acid (PLA), Acrylonitrile butadiene styrene (ABS), and Stereolithography (SLA) are commonly shown to adhere to textile substrates. However, a major disadvantage of such polymers is their rigidity and lack of elasticity, making them unsuitable for wearable applications. Researchers have thus refocused their research on flex PTC research (Kabir et al., 2020). However, there are few existing studies on flex polymers, and most have neglected the fact that TPU/TPE polymers have different adhesive properties. Additionally, there is a lack of research that compares the differences in adhesion strength between natural versus synthetic fabrics. This study will examine the variation in adhesive strength between different flex and natural/synthetic textile combinations. This study will provide further knowledge on the optimization of material partners to achieve strong adhesion in PTC. And depending on the application, practitioners may wish to customize the mechanical behaviors of PTCs, i.e., for draping, creating structure, or mobility through different polymer-textile combinations.

## Research Methods

The printing process was prepared through a fused filament fabrication (FFF) machine model i3 MK3S+ by Original Prusa. Seven types of textile substrates composed of synthetic or natural fibers were sampled in this study. Such fabrics had various levels of thicknesses (0.1mm to 0.5mm), and thus appropriate Z-axis distances (-0.800mm to -1.500mm) were identified. Furthermore, flex filaments (TPU/TPE) with a shore hardness of 40D and 82A were chosen for this study based on their different surface textures and tensile properties. A T-peel adhesive test was conducted on the PTC samples in a controlled environment of 23 Celsius with 50% relative humidity based upon an international standard ISO 11339:2010. Using an Instron 4411 tensile strength tester, the relative peel resistance of adhesive bonds between flexible-to-flexible bonded assemblies was determined. A peel speed of 100mm/min was used to identify the combability of polymers and textile substrates.

## Results & Discussion

| **Sample** | | **Peel force (N)** | | | | **Peel strength (N/mm)** | | *Minimum load (N)* | |
|---|---|---|---|---|---|---|---|---|---|
| | | *Maximum load (N)* | | *Average value (N)* | | | | | |
| **ID** | *Composition/(structure)* | TPU | TPE | TPU | TPE | TPU | TPE | TPU | TPE |
| 1 | 80%NY, 20%EA (*k*) | 82.0 | 74.0 | 73.0 | 71.1 | 2.92N/mm | 2.84N/mm | 0 | 0 |
| 2 | 100% NY (*w*) poly66 | 25.2 | 18.1 | 22.0 | 16.3 | 0.88N/mm | 0.65N/mm | 0 | 0 |
| 3 | 100% CO (*w*) coated | 14.4 | 5.1 | 13.9 | 3.8 | 0.56N/mm | 0.15N/mm | 0 | 0 |
| 4 | 100% NY (*w*) ripstop | 1.6 | 11.4 | 1.4 | 10.7 | 0.06N/mm | 0.43N/mm | 0 | 0 |
| 5 | 100% CO (*w*) plain | 6.0 | 3.0 | 4.4 | 2.6 | 0.18N/mm | 0.10N/mm | 0 | 0 |
| 6 | 100% CO (*w*) twill | 5.2 | 1.9 | 5.0 | 1.6 | 0.20N/mm | 0.06N/mm | 0 | 0 |
| 7 | 100% CO (*w*) plain | 5.5 | 3.4 | 4.4 | 2.9 | 0.18N/mm | 0.12N/mm | 0 | 0 |

*Note:* - N = newton; *k* = knit; *w* = woven; CO = cotton, EA = elastane, NY = nylon; load values are rounded to nearest digit

**Table 1.** Average peel forces and strengths of polymer-textile composite samples

T-peel tests determined the relative peel resistance of adhesive bonds between flexible-to-flexible bonded assemblies. A coefficient of variation in adhesive strengths was recorded across samples at 1.6N (Table 1) with a standard deviation of 18.7N and a mean of 11.7N. Textile and filament types were found to influence the adhesion strength. Overall synthetic & TPU have stronger adhesions than natural & TPE combinations. Synthetic knit (80%NY, 20%EA) and TPU combinations recorded a maximum load of 82.0N and peel strengths of 2.92N/mm. However, this was not the case for TPU-ripstop (100%NY) combinations which scored the lowest peel force among samples with a maximum peel force of 1.6N and a peel strength of 0.06N/mm. Overall, woven and/or natural fabrics had lower peel strengths than knit and/or synthetic fabric PTC. The reason being synthetic fabrics have better polar interaction with TPU/TPE polymers, and polymers can penetrate the pores in knitted fabric, yielding better adhesion between polymer and textile. On the other hand, woven fabrics, for example, ripstop, has too dense of a structure for TPU to penetrate through, leading to less optimal adhesion.

## Conclusion

"Inseparable" adhesion in many cases is not the best adhesion, and this study fills a fundamental research lack on the effects polymer, and textile combinations have on adhesion strength. We have demonstrated that depending on material partners (knit/weave/natural/synthetic), the adhesion strength can be controlled within a range depending on application requirements. Flex PTC remains the optimal choice for garments and other wearables due to its adaptability to our body contours and continues to challenge AM's role in developing flexible and dynamic textiles. Our results have shown synthetic knit-TPU and synthetic woven-TPU combinations to achieve adhesive strengths comparable to commercially available epoxy adhesives and high-strength bonding tapes. In conclusion, to achieve optimal adhesion in PTC, practitioners may wish to use TPU/TPE on synthetic fabrics, in particular knit, due to the pore structure found in knitted fabrics and the polar interactions between TPU/TPE and synthetic substrates.

## References

Gorlachova, M., & Mahltig, B. (2021). 3D-printing on textiles–an investigation of adhesion properties of the produced composite materials. *Journal of Polymer Research*, *28*(6), 1-10.

Kabir, S., Kim, H., & Lee, S. (2020). Characterization of 3D printed auxetic sinusoidal patterns/nylon composite fabrics. *Fibers and Polymers*, *21*(6), 1372-1381.

Kozior, T., Döpke, C., Grimmelsmann, N., Juhász Junger, I., & Ehrmann, A. (2018). Influence of fabric pretreatment on adhesion of three-dimensional printed material on textile substrates. *Advances in Mechanical Engineering*, *10*(8), 1687814018792316.

Loh, G. H., Sotayo, A., & Pei, E. (2021). Development and testing of material extrusion additive manufactured polymer–textile composites. *Fashion and Textiles*, *8*(1), 1-21.

Lussenburg, K., Van Der Velden, N., Doubrovski, Z., & Karana, E. (2014). Designing with 3D printed textiles. *Unpublished master's thesis). Delft University of Technology, Delft, The Netherlands*.

Spahiu, T., Canaj, E., & Shehi, E. (2020). 3D printing for clothing production. *Journal of Engineered Fibers and Fabrics*, *15*, 1558925020948216.