# 3D Printing of Conductive and Phosphorescent Filaments onto Textiles

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**Introduction and Significance.** Additive Manufacturing (AM) also known as 3D printing technology is a rapid production technique in which digital design data is used to build up an object. Fused Deposition Modeling (FDM), as one of the most widely used 3D printing technology, builds an object by depositing melted thermoplastic polymer filaments in a predetermined form layer-by-layer. Application of 3D printing in fashion has been studied from the perspective of designing and developing clothing and jewelry using 3D printing as an alternative realm for traditional design and manufacturing (Yap& Yeong, 2014; Vanderploeg, Lee & Mamp, 2017; Sun & Zhao, 2017). However, there have been fewer studies exploring possibility of direct 3D printing onto textiles via FDM. While most 3D printing techniques create rigid objects, deposition of polymers directly onto textiles can contribute to their flexibility, stretchability, and aesthetic qualities (River et al., 2017). Integration of 3D printing with textiles offers possibilities of application of 3D structures on the textiles for functional and aesthetic purposes and rapid production of customized products with rigid and textile based flexible parts. Although several studies exist in literature that tested direct 3D printing of common filaments such as polylactic acid (PLA), acrylonitrile butadiene styrene (ABS) and nylon (Pei, Shen &Watling, 2015; Korger et al., 2016; Rivera et al., 2017) onto textile surfaces, there is no study that analyses 3D printing of specialty filaments. This study explores 3D printing of specialty filaments of electrically conductive composite filament and phosphorescent PLA and Polyhydroxyalkanoate (PHA) blend filament on polyester knitted and cotton woven textiles. Conductive filament was selected for exploration since it can be used as connections between textile conduction lines and electrical components in electronic textile applications. Phosphorescent filament was selected as it can be used to enhance aesthetical and functional qualities of clothing. Bonding between the textile surface and the 3D printed filaments, flexibility and warping of the structures are analyzed through visual and haptic inspection. Resistance of electrically conductive composite filament printed onto different textiles was also examined.

**Materials and Methods.** Proto Pasta electrically conductive composite filament and ColorFabb PLA/PHA phosphorescent filament were printed onto cotton woven and polyester knitted textile surfaces in a 5X50X3mm rectangular shape with FDM process using a Raise3D N1 two nozzle 3D printing machine. The rectangles printed on the textile surfaces were created as CAD models, exported as .stl files to the IdeaMaker software for slicing into layers. Samples were manufactured by clamping the textile on the printing bed and extracting the filaments from the nozzle at an optimum distance and temperature. Printing temperature for the conductive filament was 235°C and 215°C for the phosphorescent filament, while printing bed temperature was

60°C. 20% infill and 40mm/s printing speed were used during all prints. A total of 20 samples were manufactured as sets of 4 different filament and textile combinations. 5 participants who have prior experience with 3D printing conducted visual and haptic inspection on the samples individually. A Likert scale rating from 1 to 5 was used by the participants in evaluating bonding (1=no bonding, 5=excellent bonding), flexibility (1=poor flexibility, 5=excellent flexibility) and warping (1=most warping, 5=no warping) characteristics of the samples. In addition, electrical resistance of Proto-Pasta conductive filament was explored. Resistance of the original filament, printed filament, printed filament on cotton and polyester textiles were measured with GWInstek GDM 8351 multimeter.

**Results and Discussion.** Conductive filament bonded better on the polyester knitted textile compared to cotton woven textile, which also affected the warping of the printed filament. Although there was no warping observed on the better-bonded polyester knitted textile surface, warping was observed on the cotton woven textile surface. Conductive filament scored poorly in flexibility as it fractured during haptic investigations. Although conductive filament is softer compared to common PLA filaments, it is very fragile and is not very suitable for applications that require flexibility. Similar to conductive filament, phosphorescent filament showed better bonding and less warping on the polyester knitted textile. It is possible to conclude that when there is better bonding between the filaments and the textiles, less warping is observed. Phosphorescent filament had moderate flexibility and can be suitable for wearable applications where they are printed in non-continuous, smaller forms on areas that require flexibility.

Table 1. Average scores for bonding, flexibility and warping of printed samples (n:5).

| Samples | Bonding (n:5) | Flexibility (n:5) | Warping( n:5) |
|---|---|---|---|
| Conductive Filament/ Cotton Woven Textile | 3 | 2 | 3 |
| Conductive Filament/ Polyester Knitted Textile | 4 | 2 | 5 |
| Phosphorescent Filament/ Cotton Woven Textile | 2 | 3 | 2 |
| Phosphorescent Filament/ Polyester Knitted Textile | 3.5 | 3 | 4 |

Conductive filament's resistance is evaluated under four conditions. The resistance of the filament increased after it was printed compared to its pure filament form. Resistance also increased more when the filament was printed on the polyester knitted textile compared to cotton woven textile. This increase may be explained by the amount of bonding between the conductive filament and the textile. The higher bonding on the polyester knitted textile is a result of conductive filament polymer molecules' diffusive penetration into the fabric structure. Therefore the level of this molecular bonding may affect the resistance of the conductive filament compared to its pure filament form and printed form on the cotton woven textile where there was less bonding.

Table 2. Resistance of conductive filament samples

| Sample (Length:50mm) | Resistance (kΩ) |
|---|---|
| Conductive Filament | 1.56 |
| Printed Conductive Filament | 2.28 |
| Printed Conductive Filament on Cotton Woven Textile | 2.39 |
| Printed Conductive Filament on Polyester Knitted Textile | 2.65 |

**Conclusion and Future Work.** The results of this study showed that specialty filaments such as conductive and phosphorescent filaments show different levels of compatibleness for direct 3D printing onto natural and synthetic textiles and conductive filament's resistance changes as it adheres on different textile surfaces. Future research will study new product development opportunities using direct 3D printing of different filaments onto textile surfaces to design wearable functional products. Launderability of textiles with 3D printed structures will also be explored.

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