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Investigation of the effect of yarn twist and flattening on the resistivity of graphite printed yarn

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ABSTRACT

The increasing demand for automated medical sector services has led to significant changes in the requirements for microstrip patch antennas. These antennas must now be highly flexible and conductive to satisfy the needs of this sector. However, achieving these requirements poses a challenging problem for researchers. In this study, we investigate the suitability of graphite-printed yarn as a viable material for flexible microstrip antennas. To achieve this, we examined the impact of yarn twist and flattening on the resistivity of graphite printed yarn. The yarns were subjected to a doubling machine, which created two-level twists in both fine and coarse yarns. The yarns were then flattened under pressure by a roller. Graphite was mechanically exfoliated using the shear method, and the prepared exfoliated graphite inks were then screen printed on the arranged strands. The results showed that the low-twist, flattened yarns exhibited good conductivity and flexibility, making them a viable material for wearable microstrip patch antennas. The flattened and graphite screen printed yarn fabrics showed promising properties for this application. Overall, this study provides insights into the use of graphite screen printed yarn as a material for flexible microstrip antennas, which is important for the development of wearable medical devices.

Keywords: Graphite ink, printed yarn, yarn twist, yarn flattening, yarn flexibility, yarn conductivity

Introduction

With the rapid development of wireless communication technology, many researchers are now paying increasing attention to the study of wireless body area networks (Eng Gee Lim, 2014). Therefore, wearable bodycentered communication has become more popular in recent research. However, several challenges hinder wearable antenna communication from performing effectively. Antennas used for wearable purposes must be flexible and comfortable as they are used in contact with the human body. Several flexible wearable antenna sensors were implemented on different types of materials, such as papers, fabrics, and plastics. Plastic substrates are neither recyclable nor biodegradable, as they contribute to environmental pollution and involve many health related problems. Alternatively, textile materials are among the most internationally used and easily available materials for the design of flexible wearable antenna sensors with regard to body area networks (BANs) (Mariam El Gharbi 1, 2020). Textile antenna sensors are expected to be used in various fields such as industry, healthcare, security, and so on. One of the prime challenges in wearable antenna implementation is to achieve structures that enable seamless integration with clothing without compromising antenna performance (Koski K. , 2015). Copper is typically used as the conductive antenna element due to its superior conductivity. However, in wearable applications, the lack of structural flexibility prevents it from effectively conforming to the surface. This calls for lightweight textile materials that provide competitive RF characteristics. The most common wearable fabrication techniques include wet-etching, inkjet printing, screen printing, and embroidery methods (KASHIF NISAR PARACHA 1 2. S., 2019). However, the coating processes of these methods to improve its conductivity reduces its flexibility and comfort. On the other hand, if a minimum amount of conducting materials is used for coating, the required conductivity of the wearable material is compromised. Therefore, it is important to devise a mechanism to optimize the compromising effect of flexibility and conductivity of the flexible wearable textile antennas.

The properties of the fabrics are determined by the properties of their constituent fibers and the structure of the fabric and/or the yarns. They are fibrous and porous materials in which the pore size, fiber density, and air volume determine the general behavior, e.g., thermal insulation and air permeability. Consistently, the density and thickness of fabrics can change with pressure as they are flexible, compressible, and stretchable materials. In addition, the fibers are constantly exchanging water molecules with the surrounding environment, which can sometimes affect their shape and properties (Mariam El Gharbi 1, 2020).

The screen-printing method of coating conductive materials to textiles is one of the viable solutions for the low-cost fabrication of wearable antennas. In this manufacturing method, the ink is pressed through a screen by using a blade. The screen consists of a mesh of fabric threads whose non image areas are blocked out using a stencil (emulsion) whereas, in the image areas, the screen is left open.

A change in fiber's cross-sectional shape has an important effect on the features of fabric, such as feel, mechanical features, comfort, etc. Several studies were carried out on the effect of fiber cross-sectional shapes on yarn and fabric properties. Babaarslan has conducted a study on flat yarn-based polyethylene terephthalate (PET) fabrics as substrates for screen printing conductive inks (BABAARSLAN, 2018). He has investigated the effect of the screenprinting parameters, such as the screen mesh size and the number of printing cycles. The uniformity of the screen-printed layers and their electrical properties are directly related to the yarn shape, substrate roughness, and printing conditions. He found that minimum average sheet resistance of $16 \pm 3\ m\Omega\ sq^{-1}$ is achieved on the flat yarn PET fabrics.

In this study, 250 tex and 80 tex count cotton yarns are produced on ring spinning with twists of 4 and 6 turns per inch and 8 and 14 turns per inch, respectively. Some yarns are hot pressed under heated pressure rollers. Graphite is mechanically exfoliated using the shear method. Graphite ink is made with an acrylic binder. All the yarns are arranged on leveled flat screen and screen printed. Resistivity and yarn relative bending rigidity are measured and compared against flattening, twisting, and count. Resistivity and relative bending rigidity of low twist and flattened yarns are observed to be decreased.

Materials and Methods

Materials and equipment used

80 tex and 250 tex cotton yarns were obtained from the spinning laboratory of Wolkite University Textile Engineering Department. Fine graphite power was purchased; acrylic binder and thickener were obtained from the Ethiopian Institute of Textile and Fashion Technology.

Electron s.r.l. A4111 voltage supplier and DL 2109 T1A moving coil ammeter were used to measure current at 12V to predict the resistivity of the yarns. Screen printing machines and heated pressure rollers were used from Wolkite University Textile & Garment Engineering Department laboratory.

Methods

Twists of the yarns selected were modified to the required level by a doubling machine. Then the yarns are pressed by heated pressure rollers 12 times. Optimum ink proportions of graphite, binder, and thickener were obtained using design expert 13 on fabrics. It is found that 78% graphene, 9% binder, and 13% thickener on weight have shown better performance on conductivity. These proportions are used to form ink for the screen printing of yarns. Yarns are arranged on leveled flat surfaces and placed on a screen printing machine and printed. Yarns were dried in an oven at 100^{o}c. The resistivity values of yarns were measured by using the four-point probe method. Self-weight relative yarn deflection values were recorded on a vertical frame that grips ruler with a projecting horizontal surface. Deflections in millimeters are recorded with projecting end lengths of 4cm, 6cm, and 8cm for each yarn.

An average deflection against its weight is obtained. Relative bending rigidity is calculated from the change in projected lengths due to deflection.

Results and Discussions

Figure1. Screen printed yarns a) non-flattened b) flattened

Yarns were arranged on a flat leveled board. Using the conducting graphite ink, the pressed and non-pressed yarns were screen printed, as shown in Figure 1. The measured results of yarn resistance and yarn relative bending rigidity are given in Table 1. Yarn resistance and bending rigidity decrease with pressing. This indicates that the requirement of wearable antenna, increased conductivity, and flexibility is achieved. Young Kim has shown that the resistivity of a material increases as a result of imperfections, such as defects, impurities, grain boundaries, and dislocations (Ji Young Kim1*, 2014). F.J. Blatt explored those vacancies and interstitials as well as other point imperfections, such as substitutional impurities,

produce measurable changes in metal conductivity in which they are present (BLATT, 1955). Based on this principle, when yarns are pressed, the inter-fiber pores are narrowed and filled with the conducting ink, which leads to reduced resistivity.

Table 1 Results of yarn resistance and relative bending rigidity

Yarn count (tex)	Twist (TPI)	Pressing condition	Regain percentage	Yarn resistance (kΩ)	Yarn relative bending rigidity index
250	4	Not pressed	19.6	5.8	0.77
250	4	Pressed	18.4	2.2	0.68
250	6	Not pressed	17.6	7.8	0.84
250	6	Pressed	16.4	4.2	0.73
80	8	Not pressed	13.6	15.8	0.64
80	8	Pressed	12.4	12.2	0.56
80	14	Not pressed	11.6	17.8	0.70
80	14	Pressed	10.4	14.2	0.59

Courser yarn shows low resistance and higher bending rigidity of yarn while yarn twist is directly related to yarn resistance. Finer yarns have a low regain percentage that leads to giving higher resistance as compared to coarser yarns. The existence of more empty spaces in low-twist yarns may make the conductive inks enter and reduce the chance of creating free spaces after printing.

Conclusion

250 tex and 80 tex yarns with low and high twists were prepared and pressed in this study. Pressed and non-pressed yarns were screen printed with graphite ink. The pressing process on yarns made it flatten and has shown high conductivity and flexibility. Higher twists and finer counts show lower conductivity as a result of lower regain percentage. Fabric made of flattened yarns or fabrics which are directly flattened can give a high performance for wearable microstrip patch antennas with high conductivity and flexibility.

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