Integration of Conductive Yarns into Fabric by Stitching

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Abstract: In the present study, the effect of stitch types on the electric conductivity of embroidered woven fabric with specially designed yarns is investigated. Two types of yarns were used to make durable, flexible and even washable layer of electric conductive yarns embroidered on the surface of woven fabric. The first type of yarns was made by frication spinning using a fine electric wire as core and cotton as sheath, while the second type is a continuous polyester filament coated with nano scale copper particles. Four types of stitches namely; fly; open chain; herringbone and chain stitches were selected. RLC meter was employed to investigate the electrical properties of the prepared samples. The electrical spectra show a lower range of frequency at which the real part of the complex conductivity,σ' (ω) values are independent of frequency. These values yield the dc conductivity σdc. The absolute values of the dc conductivity, σdc, vary over more than 4 decades upon structural variation. It is very interesting to show that the modification of the yield by loading with nano scale particle size of metals e.g. copper increases the conductivity of the yield by about four orders of magnitudes. The significant increase of the conductivity till about sub Siemens/cm is considered to be comparable with many known conductive polymers and glasses

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1. Introduction

The electro-textile applications, previously not feasible with standard textiles because of limitations in their ability to conduct current, are now becoming practical.

Although the electro textile industry is still in its infancy, it is almost certain that, in the near future, fabrics will not only protect the wearer from the environment, but will also have intelligent built in features, such as multifunctional sensors or computing devices. In contrast to rigid electronic components, the electro textile will be truly flexible soft, and comfortable to wear and touch. (1)

Conductive fibers are already being woven into experimental medical patient apparel such as jackets and vest that transmit vital signs to health care personnel. Military and law enforcement can benefit from uniforms and body armor equipped with built in sensors and computing devices. This would enhance battle field monitory by reporting vital signs and wound location on soldiers. (2)

Due to the nature of textile materials being electrical insulators, there is an urgent need to develop various types of fibers, yarns and fabrics with electrical properties to prevent some risks. The application areas for the conductive textiles are:

- Bag filters for air-filtration.
- Solvent filtration.
- Clean room for electronic assembly plant and computers.
- Carpets and conveyor belts.
- Shielding against radio and electro-magnetic waves.
- Smart apparel.(3)

Conductive threads are needed to sew and add conductive stitch to a non-conductive fabric. With conductive thread, conductivity can be added to any fabric, make conductive traces as easily as sewing, even use it as uninsulated low voltage wiring. (4)

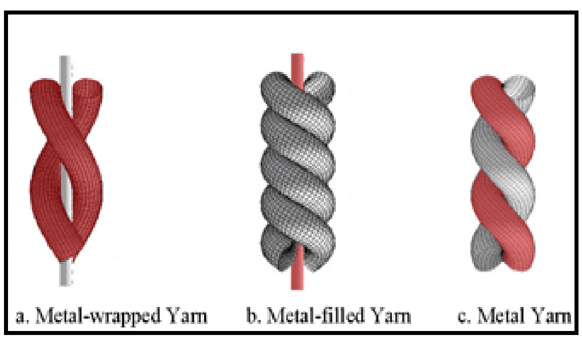


Fig. 1.Structures Of Yarns made of conductive material is shown in red.

The structures of conductive yarn can be categorized into three classes as shown in figure:

- Metal-wrapped yarn (fig.1a) is a composite of metal and yarn.
  A conductive yarn mainly consists of a strand of non-conductive yarn wrapped with one or more metal wires.
- Metal-filled yarns (fig.1b), a fine metal wire serves as a core covered by non-conductive fibers.

Textile coverings can protect a core metal wire, helping it with stand physical stresses and providing electrical insulation:

- Metal yarn does not take a core- sheath structure.
  Metal fibers that are very finely drawn replace one strand or entire strands of the yarn (fig.1c).
- Metal fibers are prepared in forms of either filaments or staple fibers and processed as a conventional yarn.(5)

2-Integration of conductive yarns into fabric:

One or more stands of the conductive yarns can be integrated into the fabric substrate to form a textile transmission line. Successful integration creates reliable conductive traces on the fabric while protecting the traces against repeated dimensional changes or abrasions in order to maintain long term conductivity.

The simplest way to embed conductive yarn into fabric is to weave it as one of the warp or weft yarns, consisting of incorporated loops, knitted structure is known for its strechability. Other techniques are performed by sewing, couching, e-briodery and printed structures.

In this research integration method is done by stitching the conductive yarns onto the fabric surface.

A conductive yarn can be stitched on the fabric surface to create a conductive trace. The stitch design is the main factor to be investigated in the present study not only for decorative purpose but it might open much potential for smart textiles.

3-Materials:

The materials used in this research included a woven fabric and the stitch yarns. The woven fabric is made of 100% cotton, 3/1 twill construction having 280 g/m^2 weight. The stitch yarns are two types:

a) Electric wire core/cotton-polyester sheath using Dref system designed by saad and El-Mogahzy(6).

b) 50/1 Nm yarn composed of 50% polyester + 50% conductive material (copper sulphide grafted onto nylon fibres PA 6.6 with a layer 0.2 microns thick of conductive copper sulphide 3.3 Dtex).

The stitch types used throughout this research are shown in figure (2) and figure (3).

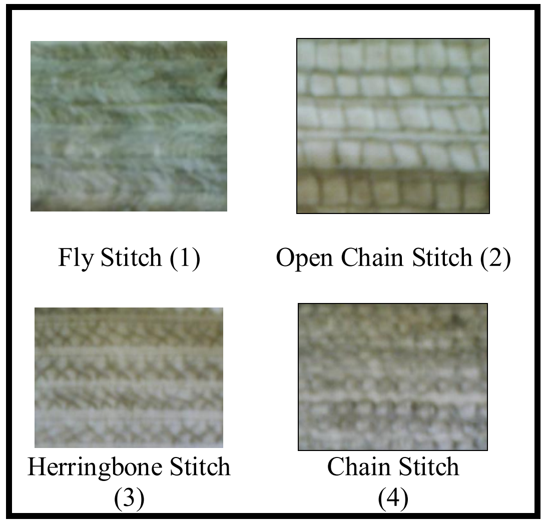


Fig. 2.Woven fabric with different stitch designusing electro-conductive yarns (nano fiber)

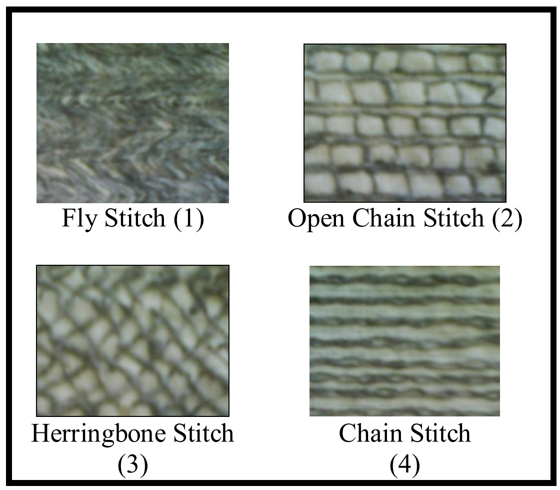


Fig. 3.Woven fabric with different stitch design using electro-conductive yarns (Core/sheath fiber)

4-Objectives:

The current manuscript aimed at checking how can the design as well as the addition of metals in nano scale affect the electrical conductivity of the investigated textiles. Generally, for the samples of relatively higher conductivity, the charge carriers are not able to follow the electric field at high frequencies but gradually travel longer distances (in atomic length scales) until an infinite percolation cluster (resulting in frequency independent value of the real part of the complex conductivity) is formed with decreasing frequency. Further decrease of frequency, shows an independence of the real part of conductivity on the frequency defined the dc conductivity σ_{dc}. The two main quantities characterizing charge transport namely: σ_{dc} (given by the value of the plateau in the real part of the complex conductivity function) and the critical frequency ($\omega_c = 2\pi f_c$), defined as the radial frequency at which the real part of the complex conductivity function begins to increase with frequency from the value of σ_{dc}.

At even lower frequencies (not shown here due to the limited frequency window used), an interfacial effects associated with the reduction of the electrical mobility due to the hindering of charge carriers by impenetrable boundaries at the external electrodes contacting the sample become dominant in the conductivity/dielectric spectra.

5- Electrical Conductivity Measurement:

Electrical measurements were performed using HIOKI Z-HITESTER 3531 LCR Bridge and HIOKI 9261 TEST FIXTURE in frequencies ranging from 42 Hz up to 1MHz (7). The method is shown in figure (4) . The bridge can measure and send to a computer the following fourteen parameters such as : Impedance |Z|, Admittance |Y|, Phase angle θ, Parallel resistance Rp, Series resistance Rs, Conductance G, Parallel capacitance Cp, Series capacitance Cs, and Dissipation factor D (tan δ) , with only four parameters in maximum can be measured simultaneously, with basic accuracy of ±0.08%. In this study we measured only the conductance G as a function of frequency in order to estimate the conductivity $\sigma'(\nu)$ [= G(ν)*d/A], where d is the thickness of the sample and A is the area of the smaller (upper) electrode. The measuring cell used in measurements (shown in figure 4) is the parallel plates cell with the upper electrode free made of copper and coated with gold with diameter 30 mm, while the lower one with diameter 50mm.

6- Results and Discussions

The real part of the complex conductivity, $\sigma'(\nu)$, is measured for all the investigated samples and illustrated graphically versus frequency as shown in the figures 5-10. Just like many systems of conducting glasses and polymers (8-10), the conductivity, of the conductive samples, becomes frequency independent at low frequencies and being equal to the dc conductivity, σ_{dc}. $\sigma'(\nu)$ follows the well known Jonscher power law (11) to some acceptable error:

$$\sigma'(\nu) = \sigma_{dc} + A\nu^s = \sigma_{dc}[1 + (\nu/\nu_c)^s] \text{---}1$$

in which, the exponent, *s,* lies between 0 and 1, ν_c characterize the onset of dc conductivity,σ_{dc}, which is related to ν_c by the Barton-Nakajima-Namikawa relation (11):

$$\sigma_o \approx 1/\tau_c \ (\tau_c = 2\pi\nu_c) \text{-----------}2$$

In other words the figures shows that the dc conductivity increases with the increase of ν_c (: decreasing of what is called hopping time,τ_c, of the charge carriers which is a microscopic parameter).

We are focusing our attention here on the dc conductivity which is represented by the lower frequency values of $\sigma'(\nu)$. The stitch is the considered parameter influencing the conductivity in figure 2, since all the four samples under investigations here are prepared using core sheath yarn technique of different sheath.

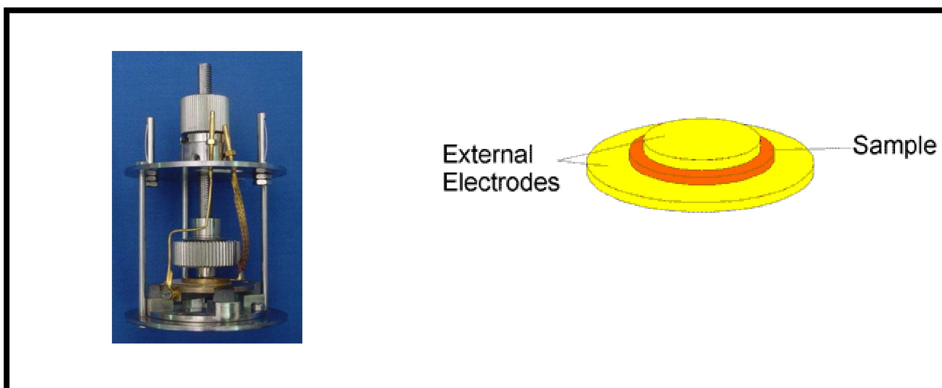
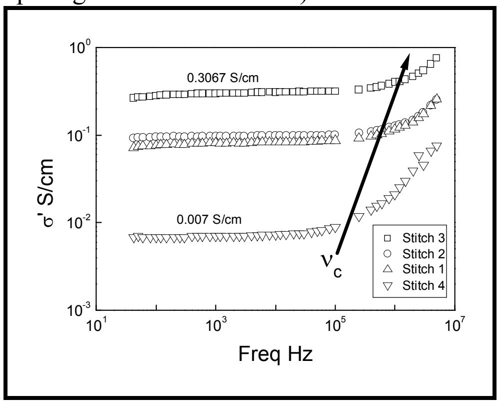


Fig.4. The sample holder and the two parallel plates condenser

6-1 Conductivity of different stitches using core/sheath yarn

It is clear from figure 5 that the highest value of the dc conductivity (about 0.3067 S/cm) is given for the stitch 3 prepared at the shorter distances between intercepts of the stitches, whereas the lowest value (about 0.007 S/cm) is found for stitch No. 4. This means that the kind of stitch increases the conductivity of the fabric by more than 40 times (comparing stitch 1 and stitch 4).



Figur 5: Comparison between conductivity of different stitches using core/sheath yarn

On the other hand the stitch of the two samples 1 and 2 is nearly the same. So, the dc conductivity values were found very close (about 0.1 S/cm). More inspection in figure 4 shows that: the longer the distance between intercepts (macroscopic parameter), the longer the hopping time of the charge carriers (microscopic parameter). The correlation between both parameters seems to be reasonable under the fact that the holes in the textile filled with air which is the highest insulator have been ever known.

6-2 Conductivity of different stitches using nano copper particle yarn

Figure 6 shows the effect of stitch on the conductivity of the polyester nano-particle copper. Comparing between the dc conductivity values of the 1g, 2h and 3c samples shows that the stitch affects remarkably again the conductivity of the samples.

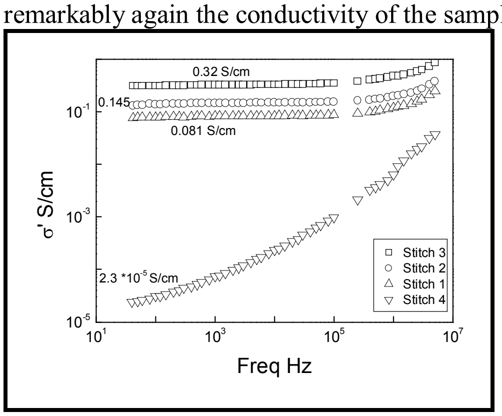


Figure 6: Comparison between conductivity of different stitches using nano copper particle yarn

Systematic change is found in the order 3>2>1 by about two orders of magnitude. Since the kind of stitch in 4 intercept points is longer the conductivity is found to be much lower than the other former three samples. The plateau represents the dc conductivity (not shown for sample 4 due to the limited range of the frequencies) suppose to be lower than 10^{-5} due to the relatively longer distances between the intercept points.

6-3 Effect of yarn type using fly stitch on fabric conductivity

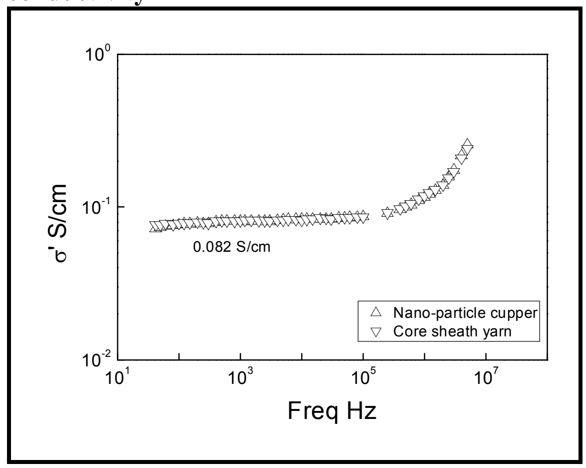


Figure 7: Effect of yarn type using fly stitch on fabric conductivity

Figure 7 shows that there is no difference between conductivity of nano composite yarn and core/sheath yarn using the fly stitch.

6-4 Effect of yarn type using open chain stitch on fabric conductivity

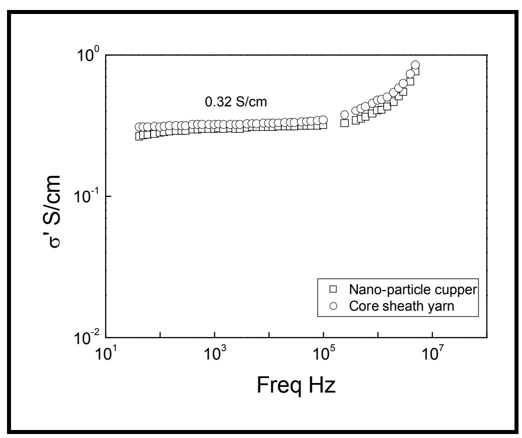


Figure 8: Effect of yarn type using open chain stitch on fabric conductivity

Slight difference is observed using the open chain stitch; this is show in figure 8.

6-5 Effect of yarn type using Herringbone stitch on fabric conductivity

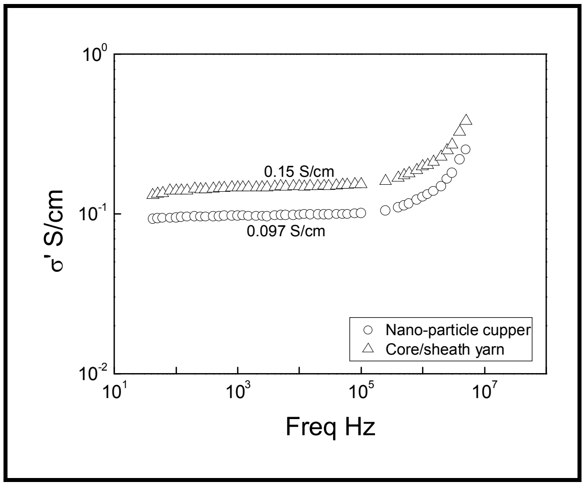


Figure 9: Effect of yarn type using Herringbone Stitch on fabric conductivity

Also, the same result is obtained using the open chain stitch (figure 9).

6-6 Effect of yarn type using Chain stitch on fabric conductivity

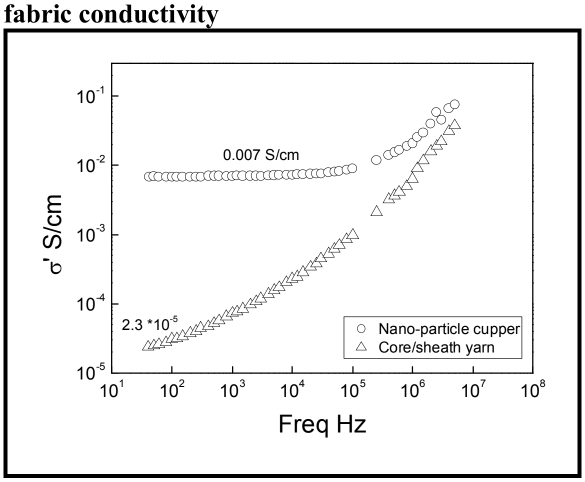


Figure 10: Effect of yarn type using Chain Stitch on fabric conductivity

In figure 10, significant difference between the conductivity of the two yarn types was obtained using the chain stitch. This can be attributed to structural nature of the two yarns.

7- Conclusions:

The integration method followed in the present work was done by stitching the two conductive yarns onto the surface of woven fabric. In general, it can be concluded that there is no clear difference between the conductivity of the samples made by using the two types of yarns for different stitches except in stitch No. 4 (the chain stitch) the nano particle yarn sample showed higher values of conductivity than core/sheath yarn sample. Some typical conclusions can be drawn as follows:

The highest value of dc conductivity was obtained for herring bone stitch using core / sheath yarn (about 40 times the chain stitch), while the values of open chain and fly stitches were nearly the same. The range of dc conductivity was 0,007 *10-2 (chain stitch) to 0,307 * 10-1 (herring bone stitch).

The same result as above is obtained using copper nano particle yarn but with a different range 2, 3*10-5 s/cm (chain stitch) to 0, 32*10-1 s/cm (herring bone stitch).

There is no difference between conductivity of core / sheath yarn using fly stitch, open chain stitch and herring bone stitch. However, significant difference between conductivity of the two yarns is found upon using chain stitch.

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