A Study on Electrical Resistance of Silver Coated Nylon Yarn with Physical Deformation

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1. INTRODUCTION

To apply a sensor, computer, and display to smart wear, power supply and communication channels should be attached. To drive theses electric devices, a electrically conductive yarn which can transfer electricity and the acquired data has been developed. Therefore, as the interest in conductive yarn has increased with increasing interest in smart wear until now. Electrically conductive yarns are categorized as multi yarn and metal coated yarn according to their manufacturing methods[1].

Especially, silver coated yarns have been used a lot in electrical conductive fabric for smart wear due to their excellent electric conductivity of silver itself and relatively low joint resistance. However, it has currently become an issue that external stimuli such as pose, strain, heat and moisture cause silver particles to separate from surface and their conductivity decreases. However, it is not only difficult to develop new substitutable and conductive materials but also electrically conductive polymers are relatively expensive. Therefore, electrically conductive yarns using silver are mainly used in smart wear.

Most of studies have been performed to increase coherence between silver coating particles and fibers, to develop manufacturing process inducible to chemical bonds such as ion bond and covalent bond. And many studies focused on measuring electric characteristics of conductive yarn. On the other hand, researches investigating resistance change according to physical change which is one of basic influential factors have not done enough yet.

In this study, we investigated theoretical resistance of silver coated conductive yarn which occurs through physical stimuli applied during human activity and clothing making processes and compared it with experimental resistance. We also analyzed resistance change of silver coated yarn and derived final equation based on this data.

2. EXPERIMENTAL

2.1 Sample preparation

The electronically conductive yarn used in this study was nylon 6.6 of 100d/24 coated with silver particles of 20wt% concentration. The sample yarn was conditioned in desiccators of temperature, 21℃ and humidity, 35% for 48 hours as being wounded in the form of cone. The characteristics of the sample are listed in Table 1.

Table 1. Characteristics of electrically conductive yarn

Fineness	Fiber diameter(㎛)	Initial modulus	Breaking strain(%)	Tenacity (kgf/d)
100/24	28.9±1.9	11.0±1.2	38.3±4.6	4.4 ±0.8

2.2 Measurement

To investigate morphological structures of electrically conductive yarns and individual fibers, using FE-SEM(JEOL, S-4200). Initial modulus, strength and elongation at break of yarns were measured for 5 repetitions by tensile testing machine, H5KT-0236 according to ASTM D2256 and their values were averaged. A special apparatus was used to measure change in electric resistance of yarn by strain.

2.3 Theoretical consideration of electrical resistance

The resistance changes of silver coated conductive yarn were calculated using Ohm's law and equation of P. Xue[2]. Their equations are as below. Where, L_0 is Initial length, A_0 is initial area, υ = Poission's ratio, ε is strain and ρ is intrinsic resistance.

$$R = \rho \frac{L_0}{A_0}(1+\varepsilon)(1+2\upsilon\varepsilon+3\upsilon^2\varepsilon^2) \qquad (1)$$

3. RESULTS AND DISCUSSION

3.1 Morphological structures

The SEM images of longitudinal view of silver coated conductive yarn without strain are shown in Fig. 1. According to Fig. 1, individual fibers are attached one another and partial splitting of silver particles was a little observed, the surface of fiber remained evenly coated.

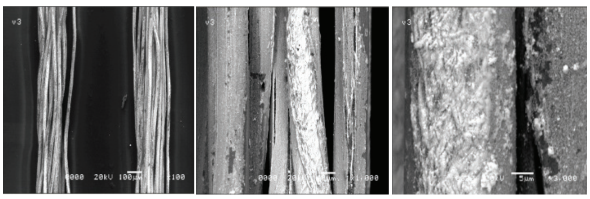
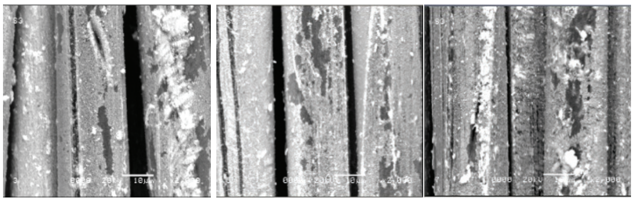


Fig. 1. SEM images of samples.

Fig. 2 shows surface change of sample yarn according to load increase. As the fiber elongates with load increase, separation of silver particles from the surface of sample yarn increased gradually. As the interval between fibers decreases and the applied load increases, contact among fibers increase. As a result, total diameter of yarn decreased.



50g 90g 150g

Fig. 2. SEM images of samples with load increase.

3.2 Resistance changes of conductive yarn with physical strain

The length change according to the load increase was converted into strain. The results of theoretical and experimental resistances are shown in Fig. 3. Theoretical resistance was calculated by multiplying the number of filament by the resistance values of individual filaments. In interval under 30% of strain, theoretical resistance was bigger than experimental resistances. Both resistances showed linearly increasing tendency. The degree of increase was bigger in experimental resistance than in theoretical resistance.

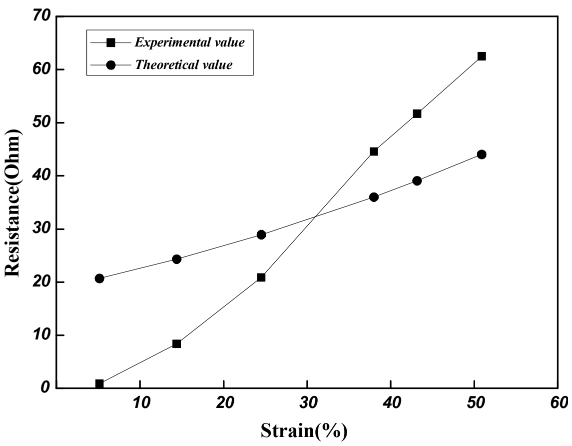


Fig. 3. Analysis of theoretical resistance.

As shown in Fig. 3, there was significant difference between theoretical and experimental resistances. Therefore, we derived the factors taking influence on surface splitting of silver particles and increase of contact area among individual fibers in consideration. The factor for resistance change due to increase of contact area can be expressed as contact constant, C and the area change due to separation of silver coating particles can be expressed as separation factor, S. Finally, equation 2 is expressed as fallow considering contact constant(C) and separation factor(S).

$$\frac{R}{L} = \left(\frac{\rho_n}{\rho_s M}\right)\rho\frac{L}{2(A_i - S)C}(1+\varepsilon)(1+2\upsilon\varepsilon+3\upsilon^2 2\varepsilon^2) \qquad (2)$$

Theoretical and experimental resistances were calculated taking separation of silver coated area and the change of contact area into consideration. Their results are shown in Fig. 4. Overall, theoretical resistance showed similar tendency with experimental resistance and better matched than the theoretical resistance which didn't take C and S factors into consideration. Theoretical resistances were bigger than the experimental resistance in all strain intervals by 17ohms on average.

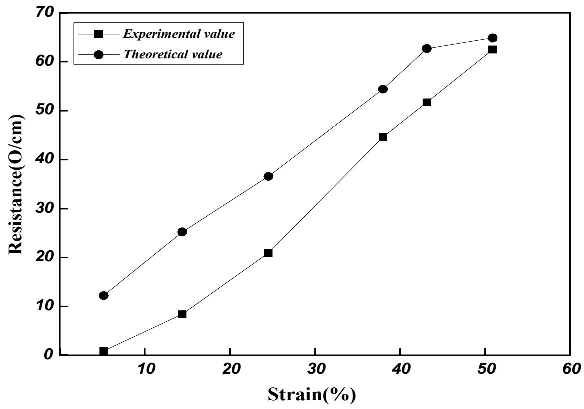


Fig. 4 Calculated resistance considering factors.

4. CONCLUSION

The list of all bibliographical references should be at the We found that the theoretical resistance suggested in previous studies has difference with the experimental resistance in this study. It is because conventional equation didn't take practical conduction area for conductive yarn manufactured as coating type into consideration. Furthermore, it did not take increase of conduction area by close build-up of fibers which take place in multi filament into account. In this study, it was confirmed that, as strain increases, resistance by splitting and separation of silver coating particles increases. We also confirmed that, as contact area among filaments increases, resistance decreases.

Therefore, we expressed influential factors for separation of silver coating particles and contact factor as equations. Based on these equations, we derived final equation and confirmed that theoretical resistance and experimental resistance have similar increasing tendency.

5. REFERENCE

[1] J. Akita, T. Shinmura, M. Toda, T. Murakami and M. Yao; *Proceedings of the 7th International Conference on Mobile Data Management (IEEE 2006)*, p.101-101

[2] P. Xue, X. M. Tao, Keith W. Y. Kwok and M. Y. Leung, *Textile research journal*, p.929-93(2004).