A Novel Method to Produce Textile-based Heating Eelements Using Chrome-Nickle MetalicWires

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ABSTRACT

There are different textile-based materials that can be used as a heating material such as silver coated, copper-plated yarns, conductive stainless steel yarns, and conductive polymers. In this study a novel and valuable method to produce heated fabrics has been proposed. Our method was based on using chrome-nickel wire with 0.05mm diameter as heat producing element because of its high electrical resistance in core-spun yarn production as core part. The core-spun yarns were produced on modified ring spinning frame and cotton fiber was selected as sheath fiber. Effect of process parameters of core-spun yarns, namely pre-tension (0, 10, 20, and 30g), feeding angle of core part related to sheath fiber(0, 15,45, and 90 degree), sheath count (8 and12Ne) and English twist factor of core-spun yarns(3.2, 3.5, and 3.8) on structural parameters, namely yarn diameter, core part position, cover factor of core part, tensile properties and generated heat of core-spun yarns was studied based on Taguchi method; therefore 16 samples were produced. The core-spun yarns were applied to DC electrical current at 11V and their heating behaviors after 2 minutes were measured using the digital thermometer based on purposed-built method. The results based on taguchi method revealed that the pre-tension on core part has the highest effect on heated produced by yarn.

KEY WORD

Core-spun yarn- Chrome Nickel Wire - Heat Generation-Taguchi Method

INTRODUCTION

Technological improvements in the field of smart and interactive materials have attracted more and more attention in recent years. These new achievements of the textile industry enable electronic devices to be directly integrated into the structure of textile, therefore modifying the functionality of the apparel [1].

The garments, which can heat the body, will possibly be one of the most widely used products for future use in daily life. Beside the medical usage, these products are developed especially for use by people who work outside during their day, such as military applications, security services, and country duties. The heating functions of the garments occur in the thermal panels [1].

Different methods to produce textile-based heating elements such as using conductive yarn in weaving and knitting process, stitching conductive yarn, conducting polymer coated fabrics by suing conductive polymers such as polypyrrole, have been proposed[1,2,3]

One of the major electrically conductive textile-based materials is carbon fiber. In a similar way, metallic fibers and steel-based yarns are also used for the same purpose. High conductive yarns are made from different materials and exist in a lot of different forms. Materials are metals like copper or stainless steel or alloys such as Nitinol, coated metals, carbon fibers, and polymers. Insulating polymers can be coated or doped [1, 2].

Conductive polymers possess a wide range of electrical conductivity values from insulating to highly conducting. Furthermore, electrical conductivity is sensitive to various external stimuli such as heat, exposure to chemicals and pressure. Such properties make conductive polymers candidate materials for applications in the fields or sensors, actuators, microwave shields and absorbers. However, the main disadvantage of these materials is that they possess poor mechanical properties. By coating conductive polymers onto textiles we produce materials, which possess excellent mechanical properties of textiles whilst retaining the desirable electrical properties of conducting polymers [2].

In 2009, a special range of continuous stainless steel filament yarns was used by Kayacan and Yazgan to obtain heating function. These yarns have a very precise electrical resistance. In this study, conductive stainless steel yarnsare chosen as a sample for metallic textile structure. The heated fabric panels produced by steel yarns are evaluated. Single and multi-ply steel fabrics were applied to electrical current and their heating behaviors are observed and compared. For this purpose, an electronic circuit that contains textile-based warming panels connected to a power supply had been developed.
They recommend that according to desired heating level the appropriate heating pad dimensions, ply or conductive yarn amounts and sufficient power supply should be applied [1].

Heat generation in fabrics coated with the conductive polymer polypyrrole was investigated by Hakansson et.al.

The PET fabrics were coated by chemical synthesis using four different oxidizing agent–dopant combinations. The antraquinone-2-sulfonic acid (AQSA) sodium salt doped polypyrrole coating was the most effective in heat generation whereas the sodium perchlorate dopant system was the least effective. The power density per unit area achieved in polypyrrole coated polyester–Lycra® fabric with 0.027 mol/l of AQSA acting as dopant was 430 W/m2. The power density per unit area achieved for the sodium perchlorate system, using the same synthesis conditions, was 55 W/m2 [3].

Tavanai et.al studied potential of polypyrrole coated polyester–Lycra® fabrics in heat generation. They also evaluated effect of weight reduction of woven fabrics on heat generation of woven fabrics. Temperatures of up to 100 ºC were obtained for an insulated roll of polypyrrole-coated fabrics [2].

Core yarns are structures consisting of two component fibers, one of which forms the center axis or core of the yarn, and the other the covering. Generally, the core is a continuous monofilament or multifilament yarn, while staple fibers are used for the outer covering or sheath of the yarn. The production of these yarns has been done successfully on many spinning systems such as ring, rotor, friction, and air jet. Among these methods, modified ring spinning frame is the first method used to produce these yarns based on simple modification of ring spinning frame. Core yarns have been used to improve the strength, durability, aesthetic and functional properties of fabrics [4, 5].

Taguchi method is a scientifically disciplined mechanism for evaluating and implementing improvements in products, processes, materials, equipment, and facilities. This method has been developed as a method based on orthogonal array experiments, which give much reduced variance for the experiment with optimum settings of control parameters. Thus, the marriage of design of experiments with optimization of control parameters to obtain best results is achieved in the taguchi method. Orthogonal arrays(OA) provide a set of well balanced (minimum) experiments and taguchi's Signal-to-Noise ratios (S/N), which are log functions of desired output, serve as objective functions for optimization, help in data analysis and prediction of optimum results[8].

In this preliminary study, a novel method to produce heated fabrics has been proposed. Our method was based on using chrome-nickel wire with 0.05mm diameter as heat producing element because of its high electrical resistance in core-spun yarn production as core part. By using taguchi effect of process parameters of core-spun yarns namely, twist factor of core-spun yarn, feeding angle of core part, pre-tension on core part, and sheath count was evaluated.

APPROACH

In this study to produce core-spun yarns chrome-nickel wire with 0.05 mm diameter as heat producing element because of its high electrical resistance was used as core part. The linear resistivity of wire was 715Ω/m. The fineness of cotton fiber used as sheath part was 4.2 micronair and its effective length was also 28 mm. The cotton roving was 09.5 Hank . The core-spun yarns were produced on modified ring spinning frame based on the proposed method of and Sawhney *et al.* [5] and Ruppenicker *et al.* [6, 7]. The schematic of used method has been shown in *Figure 1*. Cotton fiber was selected as sheath fiber.

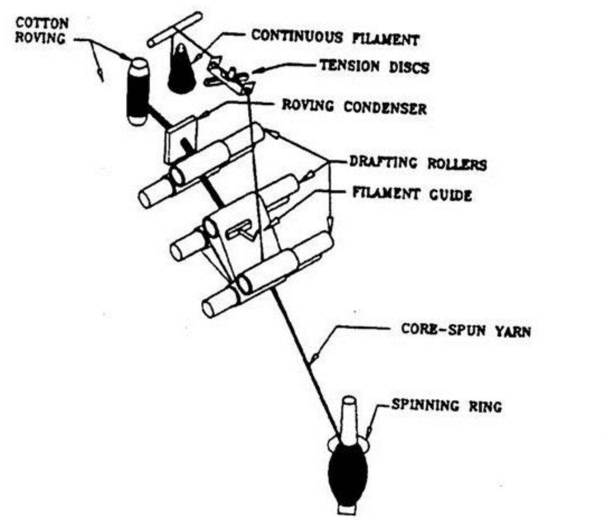


FIGURE 1. Spinning process of core-spun yarn [7]

A conventional ring spinning frame was modified to accommodate the packages of filament yarn, tension disc and a ceramic guide to produce the core-spun yarn samples. The chrome-nickel wire was fed over-end from the package, through a tension control disc and then inserted behind the top front roll directly in the center of the strand of drafted cotton fibers via a ceramic guide.

Effect of process parameters of core-spun yarns, namely pre-tension (0, 10, 20, and 30g), feeding angle of core part related to sheath fiber(0, 15,45, and 90 degree), sheath count (8 and12Ne) and English twist factor of core-spun yarns(3.2, 3.5, and 3.8) on structural parameters, namely yarn diameter, core part position, cover factor of core part, tensile properties and generated heat of core-spun yarns was studied based on L16 table taguchi method ; therefore 16 samples were produced. It should be mentioned that the last column of this table was deleted since there is only four different parameters. In *Table1* the specification of samples has been presented.

To evaluate the position of core part in yarn structure the microtome technique was applied. The tensile properties of core-spun yarns were measured according to ASTM-D2256 [9] method using Zwick tensile tester which works based on constant rate of elongation method (CRE). Yarn diameter was measured using light microscope based on length wise evaluation based on 50 observations. The samples were wound onto a red frame with1*1 cm dimension to examine and compute its cover factor. A scanner with 1200dpi resolution was used as image taking device. Optical differentiate between core part, i.e. chrome nickel wire and the sheath fibers, i.e. cotton fiber was accomplished by color difference of sheath and core part. The cover factor core part were assessed by objective method involving based on image processing technique to evaluate the percentage of core part that is visible on the surface of red frame. The core-spun yarns were applied to DC electrical current at 11V and their heating behaviors after 2 minutes were measured using the digital thermometer based on purposed-built method. In this method, the yarn was wound around the digital thermometer and two ends of samples were connected to the terminal of power supply. According to proposed method by Tavanai et.al [2], the whole roll was insulated by wrapping a wool fabric around it. The length of measurement was 30 and 60cm. Besides the temperature of bare chrome-nickel wire was measured after two minutes in both lengths. The temperature of 30 cm and 60 cm bare chrome-nickel wires were measured 50°C and 143°C respectively.

TABLE 1. Properties of samples according taguchi method

Sample	Twist factor(α_e)	Pre-tension (g)	Feeding angle	Sheath count (Ne)
1	3.2	0	0	8
2	3.2	10	45	12
3	3.2	20	15	8
4	3.2	30	90	12
5	3.5	0	45	12
6	3.5	10	00	8
7	3.5	20	90	12
8	3.5	30	15	8
9	3.8	0	15	8
10	3.8	10	90	12
11	3.8	20	45	8
12	3.8	30	0	8
13	3.2	0	90	12
14	3.8	10	15	8
15	3.2	20	45	12
16	3.5	30	0	12

RESULTS AND DISCUSSION

Yarn diameter(μm), breaking force(N), and breaking elongation of chrome-nickel core-spun yarns have been presented in *Table II* .

In Figure 2 the cross section of two samples with 400 magnification has been illustrated. Both cross sections belong to the cross section of core spun yarns with 45 degree feeding angle and 12Ne sheath count. In *Figure, (2.a)* English twist factor is 3.5, and pre-tension on core part was adjusted 20g and in *Figure (2.b)*, English twist factor is 3.8 and pre-tension was adjusted 0g. In *Table III* the temperature of samples after 2minutes have been shown. In core-spun yarn samples with 30cm length the range of measured temperature was between 17-60°C and with 60cm length was between 10-49°C. The yarn cover factor was measured based on image processing technique. The maximum cover factor was 92.97%. It means that there is not any direct contact between the metal wire and target surface and this could be another advantage of this method besides its heating behavior.

TABLE II. Physical and mechanical properties of samples

Sample Code	Yarn diameter (μm)	Breaking force(N)	Breaking elongation (%)
1	37.5(11.2)	11.10(4.45)	26.59(4.45)
2	34.92(8..36)	9.52(5.85)	78.90(8.04)
3	45.00(7.85)	9.96(6.72)	24.23(8.45)
4	33.69(5.15)	8.71(0.94)	71.83(5.41)
5	36.08(9.06)	9.52(10.51)	76.56(9.79)
6	39.58(5.66)	9.58(4.94)	22.55(20.68)
7	37.50(6.21)	7.49(12.16)	59.99(20.68)
8	44.50(8.13)	9.92(9.34)	23.82(11.59)
9	46.33(8.78)	11.00(4.22)	29.26(4.71)
10	34.08(10.11)	8.45(7.24)	72.01(9.58)
11	49.50(7.43)	10.04(6.14)	31.15(7.83)
12	50.75(9.09)	10.30(3.18)	31.43(7.25)
13	35.33(8.32)	8.43(7.31)	70.27(12.74)
14	44.16(7.5)	9.50(4.51)	28.97(8.13)
15	35.08(10.16)	9.10(8.70)	79.33(9.56)
16	34.50(8.45)	8.96(8.33)	78.57(6.40)

*Data in parenthesis are Coefficient of Variation(CV%)

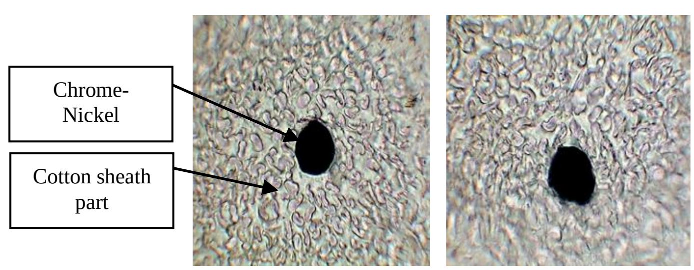


FIGURE 2. Cross section of core spun yarns with 45 degree feeding angle and 12Ne sheath count, a. English twist factor: 3.5, 20g, pre-tension; b. English twist factor: 3.8, 0g, pretension.

TABLE III. The temperature of core-spun yarn samples after 2 minutes

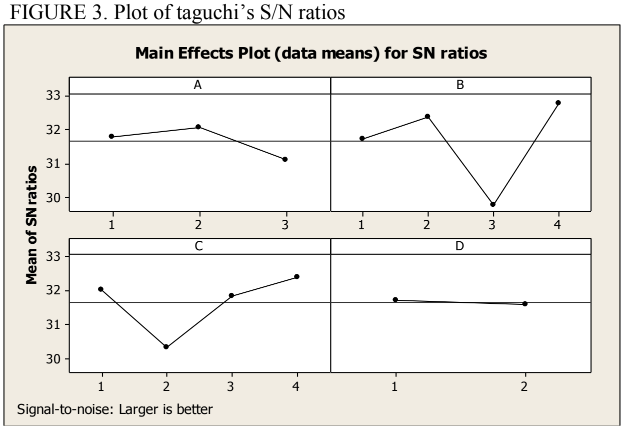
Sample Code	Δθ(°C)	Δθ(°C)
	30cm Sample	60cm Sample
1	37	22
2	34	19
3	60	14
4	54	23
5	53	31
6	43	17
7	26	10
8	37	24
9	23	17
10	44	22
11	34	15
12	38	41
13	49	25
14	46	49
15	17	20
16	47	25

The results of taguchi method for 30 cm samples have been presented in *Table IV*. Besides the plot for taguchi's S/N ratios of 30cm samples was shown in *Figure 3*.

TABLE IV. Taguchi results of heat produced by 30 cm samples after 2 minutes

Level	Twist Factor	Pre-tension	Feeding Angle	Sheath Count
1	31.77	31.72	32.02	31.71
2	32.05	32.36	30.33	31.60
3	31.12	29.78	31.85	
4		32.76	32.41	
Delta	0.94	2.99	2.08	0.11
Rank	3	1	2	4

FIGURE 3. Plot of taguchi's S/N ratios



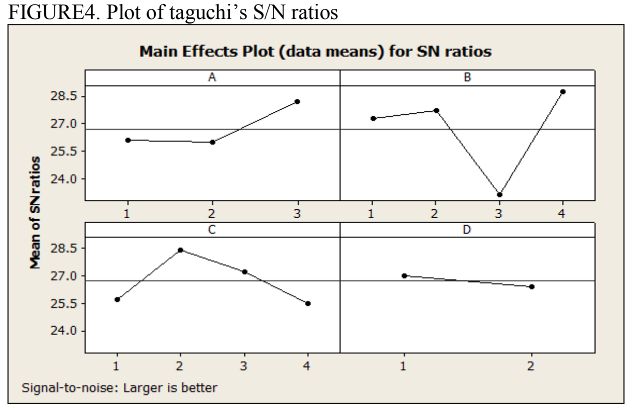
In *Table V* the obtained results of taguchi method evaluation for heat produced by 60 cm samples after 2 minutes have been shown. Besides, the plots of their S/N ratios have been shown in *Figure 4*.

The obtained results from taguchi method clearly show that the pre-tension of core part is the first effective parameter on heat generation of chrome-nickel core-spun yarns. The sheath count of core part was found as least effective parameter on heat generation of samples. According to S/N ratios, it is clear that maximum pre-tension i.e. 30g has the most effect on heat generation of core-spun yarn samples. The effectiveness of pre-tension on heat generation of samples could be explained by considering the effectiveness of this parameter on core part position in yarn structure. It seems that by increasing the pre-tension on core part , the core part is mounted in center of yarn structure. Since the sheath part act as insulating section, by positioning the core part in center of yarn structure, the heat produced that could be measured by thermometer is reduced. The obtained results revealed that count of sheath part which effect the diameter of insulating section in yarn structure does not have dominant effect on heat generation of core-spun yarn samples. Besides the changing of sheath count was not effective on heat generation of samples if we control the S/N ratios in *Figures 3 and 4*.

TABLE V. Taguchi results of heat produced by 60 cm samples after 2 minutes

Level	Twist Factor	Pre-tension	Feeding Angle	Sheath Count
1	26.09	27.31	25.73	27.02
2	26.00	27.71	28.42	26.43
3	28.21	23.12	27.23	
4		28.76	25.51	
Delta	2.21	5.65	2.91	0.59
Rank	3	1	2	4

FIGURE4. Plot of taguchi's S/N ratios



FUTURE WORKS

In our next studies we aim at study the heat generated by woven fabrics using chrome-nickel core-spun yarns and compare the potential of this method with another proposed methods by researchers such coating of fabrics, using stainless steel wires, and etc. Developing mathematical models for heat generation of this kind of yarns and woven fabrics will be focused in near future.

Finally, using this yarn in weft knitting process and compare it with woven fabrics, application of this method on different textile structures and designing the temperature controlled heating cloths are another scientific programs in this field that are on going.

CONCLUSION

In this preliminary study, a novel method to produce textile-based heating elements based on using chrome-nickel wires was proposed. The results based on taguchi method revealed that the pre-tension on core part shows the highest effect on heated produced by yarn. The position of core part in yarn structure which obviously affects the thermal behavior of yarn and textile structures could be affected by this parameter. In core-spun yarn samples with 30cm length the range of measured temperature was between 17-60°C and with 60cm length was between 10-49°C when 11V DC electrical current was applied on core-spun yarns. The yarn cover factor was measured based on image processing technique. The maximum cover factor was 92.97%. It means that there is not any direct contact between the metal wire and target surface and this could be another advantage of this method besides its heating behavior. Our finding showed the effectiveness of this method to apply as heat generation elements.

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