(REFEREED RESEARCH)

EXPERIMENTAL RESEARCH ON THE SEWABILITY OF FERROMAGNETIC MICRO-WIRES

FERROMANYETİK MİKRO TELLERİN DİKİLEBİLİRLİĞİ ÜZERİNE DENEYSEL ARAŞTIRMA

Carmen LOGHIN
"Gheorghe Asachi" Technical University
Faculty of Textiles, Leather and Industrial Management
e-mail: cloghin@tex.tuiasi.ro

Mariana URSACHE
"Gheorghe Asachi" Technical University
Faculty of Textiles, Leather and Industrial Management

Irina IONESCU
"Gheorghe Asachi" Technical University
Faculty of Textiles, Leather and Industrial Management

ABSTRACT

The paper presents the results of research on the insertion of an amorphous micro-wire with magnetic properties in linear textile structures by sewing. The micro-wires have been produced of FeBiSn alloy coated with thin glass layer. The high magnetic permeability and the small diameter (20-40 µm) recommend these wires as absorbent or reflecting element on high frequency, tens GHz range.

The analyses of the stresses specific to the sewing process emphasize the utility of the unbalanced lock-stitch structure for anchor the micro-wires on the surface of plain textiles. To evaluate the seam quality, two parameters were measured:

- the micro-wire retention in the stitch structure (Rt, cN), and
- the micro-wire tensile breaking strength changing index (%).

Key Words: Electromagnetic shielding, composite structure, unbalanced lockstitchltrasonic

ÖZET

Bu araştırmada; tekstil yapılarına doğrusal dikim yöntemi ile manyetik özellikleri olan amorf bir mikro-tel takılması üzerine araştırma sonuçları sunulmaktadır. Mikro teller ince cam tabaka ile kaplı FeBiSn alaşımdan imal edilmiştir. Yüksek manyetik geçirgenlikli ve küçük çaplı (20-40 mikron) bu teller, yüksek frekansta emici veya yansıtıcı eleman olarak onlarca GHz aralığı olarak önerilmektedir.

Dikim işleminin özel iç mukavemet analizleri, dengesiz kilit dikiş yapısının mikro tellerin düz tekstil yüzeylerindeki emniyetini vurgular. Dikiş kalitesini değerlendirmek için, iki parametre ölçülmüştür:

- -dikiş yapısında mikro-tel tutunması (Rt, cN) ve
- - mikro-tel kopma kuvvetinde gerilim değişim indeksi (%).

Anahtar Kelimeler: Elektromanyetik kaplama, kompozit yapılar, dengesiz düzdikiş

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1. INTRODUCTION

Recent research on the influence of electromagnetic fields on living organisms has shown that they interfere in a highly complex way with intracellular phenomena, cells, organs and the whole body (1). The interactions between the living organism and the environment, as well as its internal functions are influenced by the characteristics of the external electromagnetic field. The physiological effects of induced currents in the human body occur when changing the dielectric properties of the cell membrane and increasing the temperature (2, 3).

To achieve effective shielding, simple and composite materials with high electrical conductivity and magnetic permeability are used, such as:

- non-ferromagnetic metals or alloys (Cu, Ag, Ni, Au) which have some disadvantages: are heavy, break easily, and can not be used in corrosive environments;
- plastic materials coated with graphite, but which have a reduced shielding coefficient;
- ferromagnetic materials of the ferrite type;

- amorphous magnetic materials which shows stability of electrical and magnetic parameters against mechanical strains and resistance against oxidant chemical agents.

From these, textile and non-textile materials can be produced with broad uses in electromagnetic shielding: walls covering (full shielding), doors and windows covering, protection equipment for personnel working in high-intensity electromagnetic environments [4-7].

Previous research [8, 9, 12] has lead to certain textile structures with weaved metallic yarns that, although have good results regarding electromagnetic shielding, were not satisfactory in terms of usability value (high rigidity and weight, superficial friction coefficient, losing shielding capacity in time). Among the materials used for electromagnetic shielding, the most effective were metals in different shapes (solid sheet, network, powder, yarn or filament inserted in polymeric matrix), their electric conductivity being very high [13, 16, 17, 181, 19, 21]. However, these metals have the disadvantages of high density, low resistance to corrosion and difficult processing. These weak points are eliminated when using ferromagnetic micro-wires and, as an alternative, conductive polymers [14, 15, 20, 22].

Research within the national research financing framework aimed to investigate the possibilities of embedding and strengthening the ferromagnetic micro-wires made of FeBiSn or Cu and glass coated into the structure of textile matrices. The variant of ferromagnetic micro-wire inclusion into the lockstitch 301 structure, presented in this paper, has been identified as having high technological potential, with the resulting fabric having adequate shielding properties.

2. MATERIALS AND METHODS

2.1. Materials

Due to the superficial layer of glass from the structure of the ferromagnetic micro-wire, the hypotheses for establishing the research variants are:

1. Using a stitch that allows a linear disposal of the micro-wire;
2. Using a stitch that allows a firm fixing of the micro-wire.

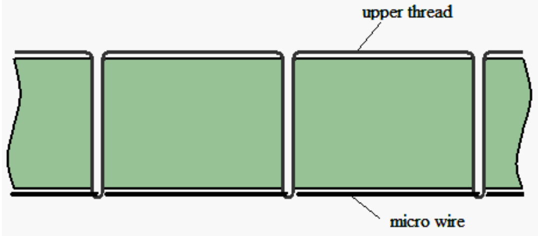


Figure 1. Insertion of the ferromagnetic micro-wire in the unbalanced lock-stitch structure

Table 1. Characteristics of the support fabrics

Article	Fibrous compositions	Structure	Friction coefficient, μ	Thickness δ (mm)	Specific weight	
					M_s (g/m^2)	γ_a (g/m^3)
1	Polyester 100%	Plain weave	0.55	0.14	63.4	0.467
2	Cotton 100%	Twill weave	0.83	0.34	149.2	0.435
3	Wool 15% PES 85%	Twill weave	0.87	0.72	272.7	0.379

These two conditions were simultaneously cumulated in the lockstitch 301, the unbalanced form, with the ferromagnetic micro-wire on the bobbin case (figure 1).

Both the geometric-structural characteristics and the ones concerning the surface aspect for the fabrics used as support are presented in Table 1.

Yarns used for sewing:

- for the needle: sewing thread PES Epic 120;
- on the bobbin case: micro wire ferromagnetic alloy FeBiSn coated with glass, 50 μm in diameter.

2.2. Methods

Two assessment indicators were used for evaluating the quality of the seam and the sewing properties of the ferromagnetic yarn:

- the *micro-wire retention in the stitch structure (R_t, cN),* and
- the *micro-wire tensile breaking strength changing index (R_p,%).*

An original method for the evaluation of the micro-wire retention in the stitch structure was proposed. This method establishes the value necessary for detaching the micro wire (R_t) from the stitch structure, at longitudinal stress (tangential in relation to the fabric surface), when the fabric is fixed in the upper clamp of the H5K-T Tinius Olsen dynamometer and the micro wire is fixed in the bottom clamp (figure 2). The initial distance between the two clamps was of 10 cm, and the length of the stitch line of 1 cm.

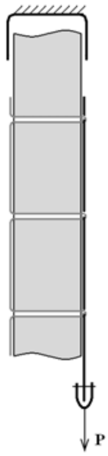


Figure 2. Fixing the specimen in the dynamometer clamps

The evaluation of the quality after sewing of the micro wire placed in the structure of the stitch was made by calculating the tensile breaking strength changing index, R_P (relation 1):

$$R_P = \frac{P_0 - P_c}{P_0} x100 \quad (\%) \qquad (1)$$

where: P_0 – represents the breaking tensile of the micro wire before sewing;

P_c - represents the breaking tensile of the micro wire after sewing

In order to determine the tensile breaking of the micro wire after sewing, it needed to be carefully extracted from the stitch so that there was no additional stress. The upper thread was cut between two stitches and the bottom micro-wire was be extracted al the inferior level of the seam (figure 3).

Based on the stress complex involved in the sewing process when using 301 stitch, the following factors were considered important:

- the surface state of the fabric used for ferromagnetic micro wire sewing (friction coefficient);
- upper thread strength;
- structural parameters of the seam.

The characteristics of the fabric used for sewing with the ferromagnetic micro-wire lead to different trends in the relationship between the stitch balance and the tensions generated in the threads. In addition, the retention of the micro wire in the stitch structure was in close correlation with the surface aspect of the fabric.

The braking tension of the needle thread (the active thread) can be considered as a control variable, but this does not imply that the tensions generated in the follower thread can be treated passively. The position of the interlacing point (figure 4a, b, c) is achieved by means of standard technical adjustment of the upper thread tension at three value levels.

The different tensions of the upper thread were established by calculus, knowing the elements of the tensioning device and considering three different values for the arrow of the spiral spring. Thus, the calculated values for the upper thread tension were: $T_{s,1}$= 46 cN, $T_{s,2}$=102 cN, $T_{s,3}$=158 cN.

The structural parameters of the seam, stitch length (p) and thickness (δ) were the essential geometrical parameters in that case. In addition, a new indicator, thickness - stitch length ratio, *s,* was calculated (using formula 2) with a significant role in the stitch balance.

$$s = \frac{\delta}{p} \qquad (2)$$

where: δ – represents the thickness of the fabric, mm;

p – stitch length, mm.

The stitch balance, an important factor in the retention of the ferromagnetic micro-wire, is appreciated by the so called “migration” coefficient of the interlacing point in the fabric, *u* (formula 3).

$$u = 0.5 \cdot \left(1 - \frac{R_l - 1}{R_l + 1} \cdot \frac{1 + s}{s}\right) \qquad (3)$$

where: s – represents the thickness - stitch length ratio;

R_l – ratio between the lengths of the upper thread (l_s) and lower thread (l_i) used in a stitch length,

$$R = \frac{l_s}{l_i} \qquad (4)$$

The planned variation levels emphasizing the influential factors are presented in Table 2.

3. RESULTS AND DISCUSSION

The parameters for evaluation of the two proposed indicators for assessing the ferromagnetic micro-wire retention (R_t) in the stitch structure and the integrity of its quality (R_p), were determined for each set of samples resulted after the sewing tests.

Mathematical modelling based on experimental results initially required a statistical analysis of the original data in order to evaluate the significance of each factor under consideration, thus making it possible to order these factors in terms of influence.

For the preliminary experiment, the mono-factorial dispersion analysis was used, the experiments being conducted according to a program in which each factor under analysis was modified at three levels (m = 3). For each level, five (n = 5) parallel determinations were performed.

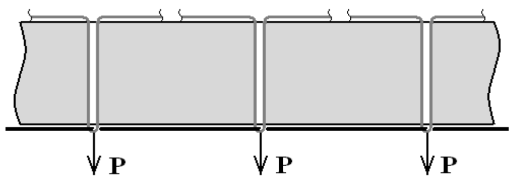


Figure 3. Extracting of the micro-wire from the stitch structure

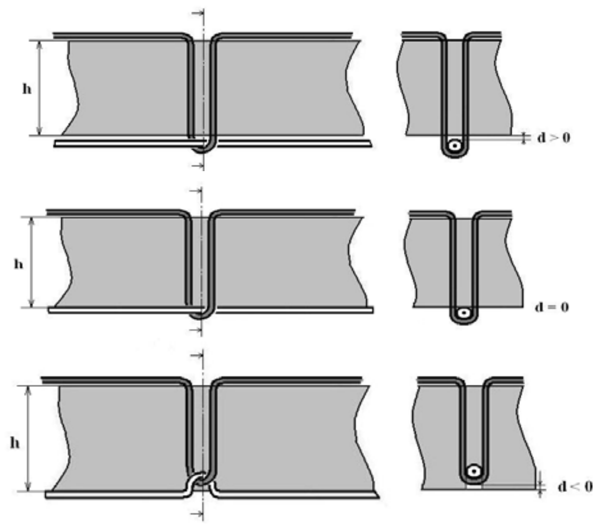


Figure 4. The aspect of the 301 lockstitch for different tensions of the upper thread

Table 2. Levels of planned variation for influential factors

Variation factor	Level	Value
Support fabric (frictional coefficient)	minimum	0.55
	medium	0.83
	maximum	0.87
Stitch length, p (mm)	minimum	1.5
	medium	2.5
	maximum	3.5
Upper thread tension, T_s (cN)	minimum	46
	medium	102
	maximum	158

3.1. Retention of the ferromagnetic micro-wire in the stitch structure

In the set of experiments we considered necessary to investigate the unbalance state of the stitch structure that included the ferromagnetic micro-wire.

The migration coefficient of the threads interlacing point (**u**) was calculated and the results are summarized in Table 3.

One can notice that in case of articles 2 and 3, the migration coefficient was practically 0. In case of article 1, u = 0,1. If we consider that the thickness of this variant was 0,14mm, we can see that the absolute level to which the interlacing point rises is only 0,014mm, which allow us to say that the micro-wire remains in the inferior surface (figure 5).

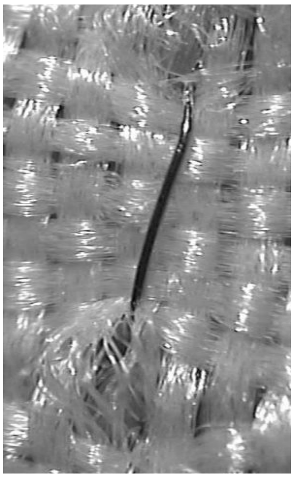
The experimental program, results and statistical indicators related to the dispersional analysis in case of ferromagnetic micro-wire retention in the stitch structure are presented in Table 4.

From the analysis of the experimental results one can notice that the ferromagnetic micro-wire retention in the stitch structure increases with the increase of the textile material specific weight. The increase rate is bigger in the domain of high specific weight values, even if the specific weight increase is, in absolute terms, approximately the same as in the first interval. Also, it can be observed that the ferromagnetic micro-wire retention increases more significantly in the second variation domain of friction coefficient (μ = 0,83 – 0,87). Concerning the influence of the stitch length, one can notice the decreasing trend of the ferromagnetic micro-wire retention correlated with the increase of the stitch length. The explanation lies in the decrease of the micro-wire interlacing point frequency in the seam structure. This confirms the initial hypothesis that needle thread tension is a significant factor influencing the balance of the stitch and thus on the retention of the inferior thread in the stitch structure. A significant increase of retention is observed, approximately 10 fold, in the range of variation for needle thread tension (46 – 158 cN).

The statistical data analysis leads to the conclusion that the ferromagnetic micro-wire retention in the stitch structure, R_t, is influenced firstly by the needle thread tension (F_c=480,42), then by the stitch length value (F_c=127,38) and, last but not least, by the fabric surface state on which the ferromagnetic micro-wire is inserted (F_c=96,61). Total dispersion values are between 10617.27 and 10920.47 in case of the upper thread tension, article and stitch length.

Table 3. Evaluation of the imbalance state of the seam (p = 2,5 mm)

Article	Length of upper thread l_s, mm	Length of lower thread l_i, mm	Length ratio R_l	Thickness δ, mm	Thickness - stitch length ratio **s**	Migration coefficient **u**
1	5	4,6	1.08	0,14	0,055	0,1
2	4,6	3,7	1,24	0,34	0,136	0,055
3	5,3	3,6	1,47	0,72	0,288	0,075


Article 1


Article 2

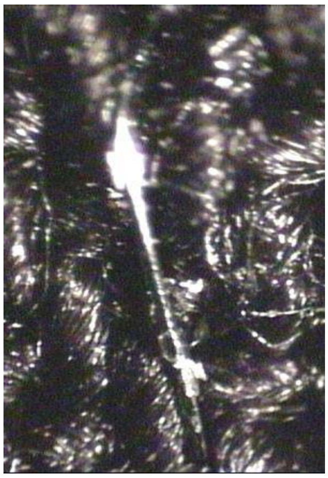

Article 3

Figure 5. Image of the stitch inferior surface in case of different fabrics (x50)

Table 4. Variation of ferromagnetic micro-wire retention in the stitch structure

Nr. det.	Ferromagnetic micro-wire retention, Rt (cN)								
	Article			Stitch length (mm)			Needle thread tension (cN)		
	1	2	3	1,5	2,5	3,5	46	102	158
1	50	69	152	142	83	43	10	50	94
2	64	79	129	163	84	49	7	37	102
3	71	78	165	143	104	54	7	46	91
4	51	79	151	134	99	51	6	47	105
5	62	84	134	131	94	49	5	40	101
Avg.	59,5	77,8	146,2	142,6	92,8	49,2	7	44	98,6
S^2	10.424,47			10.920,47			10.617,27		
S^2_0	107,9			85,73			22,1		
S^2_A	2.063,31			2.167,95			2.119,03		
F_c	96,61			127,38			480,42		

For each factor, the residual dispersion, S^2_0, amounted to very weak influence (compared to the total dispersion), from 0.21 to 3.76%, in case of all influential factors.

3.2. Quality changes of the ferromagnetic micro-wire breaking strength

The average breaking strength value of the ferromagnetic micro-wire, determined before the sewing process, was of 574 cN. According to the method presented in chapter 2.2., the reduction of the micro-wire breaking strength index R_p was determined. The microscopic aspect of the ferromagnetic wire in the two situations, before and after sewing, is presented in figure 6.

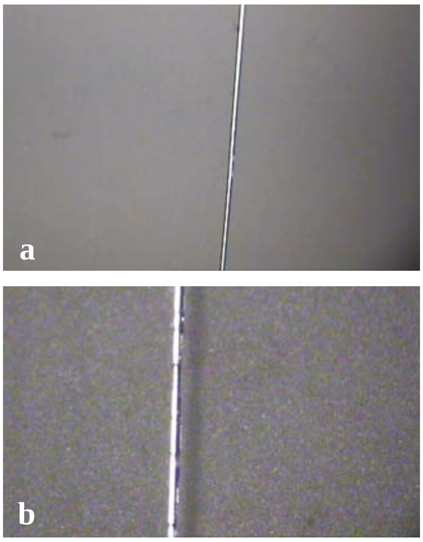


Figure 6. Microscopic aspect of the ferromagnetic micro-wire

(a) – before sewing; (b) – after sewing;

The experimental program, results and statistical indicators of the dispersion analysis for the reduction of the ferromagnetic micro-wire breaking strength after sewing are presented in Table 5.

The influence of the support fabric surface on the reduction of the breaking strength is significant, but it is more obvious for item 3 with maximum specific weight and frictional coefficient at the same time. The stitch length increase leads to a frequency reduction in the bending stress produced when the lower thread crosses the eye of the needle plate. As a result, we can expect a reduction of the breaking strength with the increase of stitch length, and this is obvious for stitch length values between 2,5mm and 3,5 mm. At the same time, the advance of the seam element is made on a longer distance and the feeding force influences the thread tension, leading to a greater physical load. This second hypothesis can explain the growing trend of the indicator (R_P) on the variation field of 1.5 – 2.5 mm stitch length.

The increase of the upper thread tension leads to a higher degradation of the ferromagnetic micro wire, but the variation range of the breaking strength reduction is very narrow (51 – 56%). The explanation may lie in the destruction of the protective layer of the ferromagnetic micro wire, occurrence of oxidation and a bigger breaking risk.

4. CONCLUSIONS

1. Technological sewing tests were made for the insertion of ferromagnetic micro-wires in the structure of the lockstitch, in the unbalanced form, in order to maximize mechanical protection of the ferromagnetic micro wire.
2. The main influential factors affecting the seam quality were considered and an analysis of their significance was performed.
3. The retention of the ferromagnetic micro-wire in the textile linear matrix (in this case stitches made in different conditions) was determined as the force necessary to extract the micro wire from the stitch structure. This was one of the main indicators for the evaluation of the seam quality.
4. The degradation of the ferromagnetic micro wire at sewing was evaluated by its breaking strength reduction. Generally, the degradation values are high (35 –58% of the initial resistance), leading to the hypothesis that the glass coat cracks, allowing for the oxidation of the micro wire to occur.
5. The ferromagnetic micro-wire suffered physical degradations even in the stage of sewing preparation, when winding on the bobbin and unwinding in the feeding process. In order to verify this hypothesis, the breaking strength of the micro-wire feed from the bobbin case was identified and a similar calculation measured the destruction indicator at 24.6%.
6. As fabric support for the insertion of the ferromagnetic micro wire by sewing, item 2 is recommended, that is cotton weave with medium specific weight and friction coefficient of 0.83.
7. For maximum protection of the ferromagnetic micro wire, minimum tension in the needle thread is recommended ($T_s \approx 50cN$).
8. The statistical analysis on the influence of the independent variables (process factors) over the quality indicators of the ferromagnetic micro wire sewing (process functions) can describe the factors-functions influence. The ordering is made according to the calculated Fischer Criteria value (F_c) as in Table 6.

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Table 5. Variation of the reducing of the ferromagnetic micro-wire breaking strength after sewing

No. of the experiment	Reduction of the ferromagnetic micro-wire breaking strength, R_p (%)								
	Article			Stitch length (mm)			Needle thread tension (cN)		
	1	2	3	1,5	2,5	3,5	46	102	158
1	48.43	47.91	44.95	53.14	56.27	54.18	48.61	57.04	54.71
2	46.86	37.98	54.88	52.09	57.49	49.13	54.53	56.45	54.88
3	40.42	37.28	52.96	53.31	60.11	60.28	52.96	52.19	60.28
4	41.46	45.12	46.86	53.66	61.32	45.29	47.91	53.66	52.26
5	48.43	43.38	51.22	53.48	57.84	38.68	51.02	51.87	56.45
Average	45.12	42.33	50.17	53.13	58.60	49.51	51.00	54.24	55.71
S^2	78.98			104.8			29.03		
S^2_0	17.85			24.29			7.46		
S^2_A	12.22			16.1			19.93		
F_c	4.43			4.31			3.89		

Table 6. Ranking of the factors functions influence

No.	Fischer criteria (F_c)	Process factors	Process factors
1	480.42	Needle thread tension	Retention
2	127.38	Stitch length	Retention
3	96.61	Support fabric	Retention
5	4.43	Support fabric	Resistance decreasing
6	4.31	Stitch length	Resistance decreasing
7	3.89	Needle thread tension	Resistance decreasing

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