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BENDING BEHAVIOUR OF MAGNETIC COTTON YARNS

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Abstract**:** *Magnetic yarns are composite yarns, i.e. they combine elements of various natures and properties, with proven potential for electromagnetic interference (EMI) shielding. In this paper, different mixtures of hard and soft magnetic powder were chosen to cover materials made of cotton yarn. The physical properties and bending behaviour of the produced composite yarns were investigated in order to evaluate the yarns for further textile processing.The cotton yarn used as base material was covered with hard (barium hexaferrite* $BaFe_{12}O_{19}$*) and soft (Black Toner) magnetic particles. An in-house developed laboratory equipment has been used to cover the twist cotton yarns with seven mixtures having different amounts of magnetic powder (30% – 50%). The bending behavior of the coated yarns was evaluated based on the average width of cracks which appeared on the yarn surface after repeated flexural tests. The obtained results revealed that usage of a polyurethane adhesive in the coating solution prevents crack formation on the surface of hard magnetic yarns after flexural tests. At the same time, the higher the mass percentage of hard magnetic powder in the mixture, the higher was the cracks' width. The soft magnetic yarns are more flexible and a smaller crack width is observed on their surface. Both the coating solution composition and the powder diameter are expected to influence the bending behaviour of coated yarns.*

Key words: *coated cotton yarn, hard and soft magnetic powder, bending behaviour*

1. INTRODUCTION

Nowadays textile materials go well beyond common domestic use finding applications in various fields such as agriculture, construction and medicine. During the last decade, there is a growing interest in the field of intelligent textiles, which are textiles that are sensitive to changes in the environment through a series of features such as: electrical conductivity [1]; photo-luminescence; UV protection; catalytic and antistatic characteristics; antimicrobial and self-cleaning characteristics, that prevent or limit the spread of fire; magnetic and electromagnetic shielding properties [2]. Among these, magnetic textiles are becoming increasingly popular and demanded due to their well-known special properties confered by the functionalization with magnetic elements in powder form.

Magnetic micro/nano powders are known for their application in electromagnetic interference (EMI) shielding which gives rise to many problems as electronic equipment operates in close proximity [3]. Consequently, potential applications can be foreseen in communications, computations, automations, space, medicine, etc.

In the literature, the term "magnetic textile yarns" defines yarns containing electro-conductive metal fibers. The main characteristics of such yarns is ferromagnetism, i.e. they exhibit magnetic properties in the presence of an external magnetic field. Magnetic wires lead to different magnetic anisotropies according to the textile structure type in which they are inserted and their position in the structure. Thus, the magnetic properties of yarns inserted in different textile structures can be diverse and can be tuned to create suitable structures, customized according to the requirements of the targeted application [4], [5].

From structural point of view, magnetic yarns are composite yarns, i.e. they combine elements of various natures and properties. Their composition can contain spun twisted yarns, with or without core, with various structures and components. According to recent research, the inclusion of magnetic particles in the yarns transforms them into magnetic yarns [6], [7]. The yarns may contain both diamagnetic fibers (natural, artificial or synthetic) and fibers with permanent magnetic field and may be used in woven or knitted structures, with various geometries, depending on the polarity of the inserted yarn.

The magnetic characteristics can be obtained by using electro-conductive fibers in the yarn structure, introduction of magnetic powder into the fiber matter during fiber production or by coating with solutions having magnetic properties [3], [4].

In this paper, different mixtures of hard and soft magnetic powder were chosen to cover materials made of cotton yarn. The physical properties and bending behaviour of the produced composite yarns were investigated in order to evaluate the yarns for further textile processing.

2. MATERIALS AND METHOD

2.1 Materials

In this article, the reference yarn (consisting of three simple yarns) used as reinforcing element was a 100% cotton yarn with Z twist direction and 930 twists/m. Each single combed ring-spun yarn had S twist direction with 1058 twists/m, while the fineness was 10 tex.

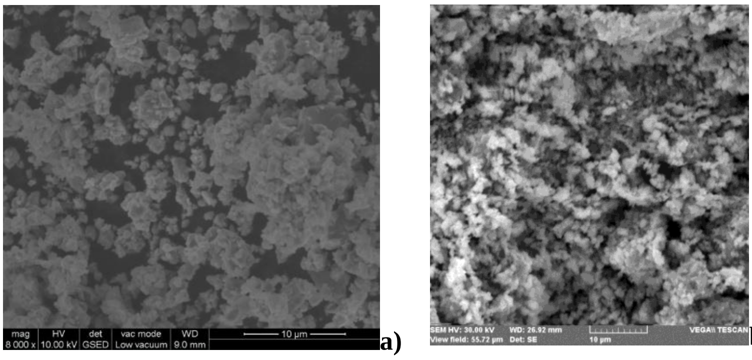
Barium hexaferrite (BaFe), a hexagonal hard magnetic ferrite with a magnetoplumbite structure, which is a widely used ceramic permanent magnet, was supplied by Rofep, Romania. Black Toner 6745 CP-313, a composite, soft magnetic mixture powder (denoted as CP-313) widely used as ink carrier during the printing process, was purchased from Lanier Worldwide Inc. U.S.A. The basic characteristics of these magnetic materials are presented in Table 1.

Table 1: *Basic characteristics of magnetic materials*

Characteristic	**Value**	
Name	isotropic barium ferrite 1,	black toner
Class	hard ferromagnetic materials	soft ferromagnetic material
Chemical formula	$BaFe_{12}O_{19}$	mixture
Components	Fe_2O_3 and $BaCO_3$	Styrene acrylate resin (60-90%), Carbon black (5-10 %), Polypropylene wax (1-5 %), Organic pigment (0,5-1%), Silica (<1 %)

Average diameter	4-6 µm	1-2µm
Measured density	4458 kg/m^3	658 kg/m^3

Two SEM images of the BaFe and CP-313 sample are given in Fig. 1.



a) b)

Fig. 1. *SEM images of (a) BaFe and (b) CP-313.*

Seven mixtures of hard and soft magnetic powder having different mass percentage of two polymers in viscous state (polyvinyl acetate PVAc and polyurethane resin PUR) and glycerol based plasticizer were used to cover the cotton yarns (see Table 2). Polyvinyl acetate is a widely used thermoplastic adhesive with good adherence to cellulosic materials. Polyurethane is used as adhesive due to its remarkable adherence.

Table 2: *Composition of coating solutions*

Yarns code	**Type of core**	**Componets (wt%)**
A1	100% cotton yarn	30% BaFe, 69% PVAc, 1% Gly
A2		40% BaFe, 50% PVAc,10% PUR
A3		45% BaFe, 52% PVAc, 3% Gly
A4		50% BaFe, 50% PUR
A5		30% CP-313, 45% PVAc, 10% PUR, 5% Gly
A6		40% CP-313, 57% PVAc, 3% Gly
A7		42,5 % CP-313, 54,5% PVAc, 3% Gly

2.2 Methodology

An in-house developed laboratory equipment, schematically depicted in Fig. 3, was used for coating. This laboratory device allows a primary orientation of the magnetic particles along an external electromagnetic field lines having a 0.14 T induction. Subsequently, the coated yarn was subjected to a more powerful magnetization until saturation.

The deposition process occurs in the magnetic mixture feed chamber which is equipped with a special calibration device spinneret type with a circular hole (500 µm in diameter). This ensures a uniform deposition of the polymer mixture. It also allows covering yarns having an average apparent diameter of less than 400 µm. After calibration, the coated yarn passes through a multi-polar magnetizing device having an induction of 0.7 T. The final stages of the process include heating, fixing of the coated layer and winding. The trajectory of the yarn during the deposition process causes the magnetic solution to adhere on its surface between the fibers of the surface layer.

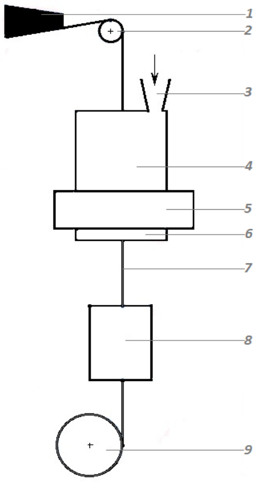


Fig. 3. *Coating in-house equipment: 1- bobbin yarn, 2 - guiding yarn device, 3- polymeric solution feeder, 4 - coating chamber, 5- air gap induction electromagnet, 6 - spinneret, 7 - coated yarn, 8 - dryer, 9 - winding drive*

The coated yarn samples were conditioned in a standard atmosphere of 65%±2% R.H. and a temperature of 20±2^{0}C in order to investigate their structural modifications and bending behavior.

In order to estimate the bending behavior of coated yarns, a Tilmet 88 device was used [8]. Testing involved repeated flexural cycles (45 cycles/min) at an angle of 60^0 over a period of 11 minutes. All tests were repeated five times.

The samples had a length of 6 mm, which ensures enough space to identify the number of cracks formed on the coated yarn surface after repeated tests. The surface of the coated yarns was studied using a microscope type Olympus SZX 10 at a 9.45X magnification degree.

3. RESULTS AND DISCUSSION

The bending behavior of the coated yarns was evaluated based on the average width of cracks which appeared on the yarn surface after repeated flexural tests. Microscopic images taken at a magnification of x 9.45 were used to determine the values of the width.

Three optical images of coated yarns (sample A1 and A2 covered with hard magnetic powder; sample A6 covered with soft magnetic powder) after the third test are given in Fig. 4.

a) b) c)

Fig.4: *Microscope images: a) yarn A1 after 3rd flexural test, b) yarn A2 after 3rd flexural test and c) yarn A6 after 3rd flexural test*

The values of the average cracks' width, expressed in µm, are given in Table 4 and the graphic representations are presented in Fig. 5 and Fig. 6.

Table 4: *Tests results of measured yarns*

		Coated yarn						
		A1	**A2**	**A3**	**A4**	**A5**	**A6**	**A7**
Average width (µm)	Before I-st test	7	0	8	0	5	10	3
	After I-st test	9	0	16	0	8	10	13
	After II-nd test	14	0	22	0	8	17	14
	After III-rd test	14	0	23	0	8	23	16
	After IV-th test	24	0	25	0	9	27	20
	After V-th test	25	0	27	0	12	35	20

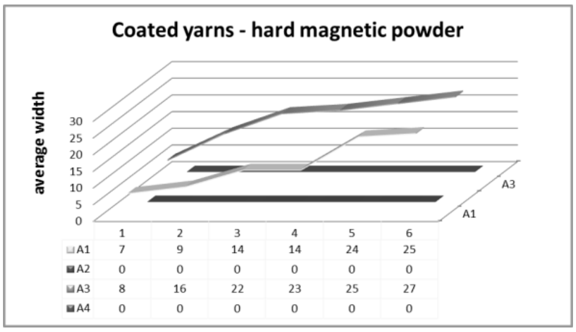


Fig. 5. *Average width of coated yarns A1-A4*

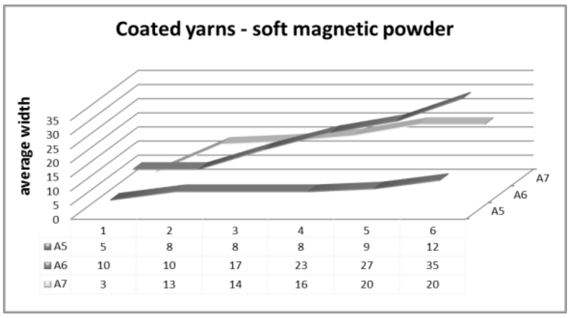


Fig. 6. *Average width of coated yarns A5-A7*

It is observed from Table 4 that, after repeated flexural tests the surface of samples A1 and A3 exhibits cracks. For example, a 15% increase of hard magnetic powder mass percentage when comparing A1 and A3 is leading to a 56% increasing of crack width after the 1st test. On the contrary, samples A2 and A4 are crack free which we believe is due to the presence of the PUR in the coating solution (see Table 2). PUR has a good elasticity due to a high weight percent of solid content (>99%) and low content of volatile products (<1%).

In the case of soft magnetic yarns, A5 to A7, these yarns are more flexible than hard magnetic yarns due to the average diameter of black toner that is smaller than isotropic barium ferrite. Thus, a lower cracks' width is observed on the surface of the soft magnetic yarns as compared to the hard magnetic yarns, having almost the same composition of the coating solution (e.g. A3 versus A7).

4. CONCLUSIONS

In this work, we have successfully prepared and characterized both hard and soft magnetic powder coatings on cotton yarns with respect to their bending behaviour. Seven coating solutions with various mass percentages of hard and soft magnetic powders, two polymers in liquid state and a glycerol were used in order to obtain coated yarns. An in-house developed laboratory equipment was employed for the coating process.

Bending tests involved repeated flexural cycles (45 cycles/min) at an angle of 60^0 over a period of 11 minutes. The evaluation of the bending behaviour indicated that the appearance of cracks on hard magnetic cotton yarns depends on the usage of the polyurethane adhesive in the coating solution. The higher mass percentage of hard magnetic powder from coating solution the higher is the crack width because yarns become more stiff.

For soft magnetic yarns, the average diameter of the black toner particles is smaller than in the case of isotropic barium ferrite. Consequently, these coated yarns are more flexible and a smaller crack width is observed on their surface. In conclusion, both the coating solution composition and the powder diameter are expected to influence the bending behaviour of coated yarns. Both these parameters can be tuned according to the desired application.

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