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Magnetic Cellulose Fibres and Their Application in Textronics

Abstract
In this article the mechanical and magnetic properties of magnetic fibre based on experimental investigation are described. These magnetic fibres, made up of cellulose matrix and powdered magnetic modifier, were used to build textile magnetical coils with a textile core. Textile magnetic coils are elements of electrical and electronic devices, such as induction sensors and electromagnetic actuators. From magnetic fibres we made magnetic nonwoven which can be used as magnetic shields.

Key words: *magnetic fillers, magnetic fibres, magnetic textile elements, magnetic coils, textronics, electromagnetic shield.*

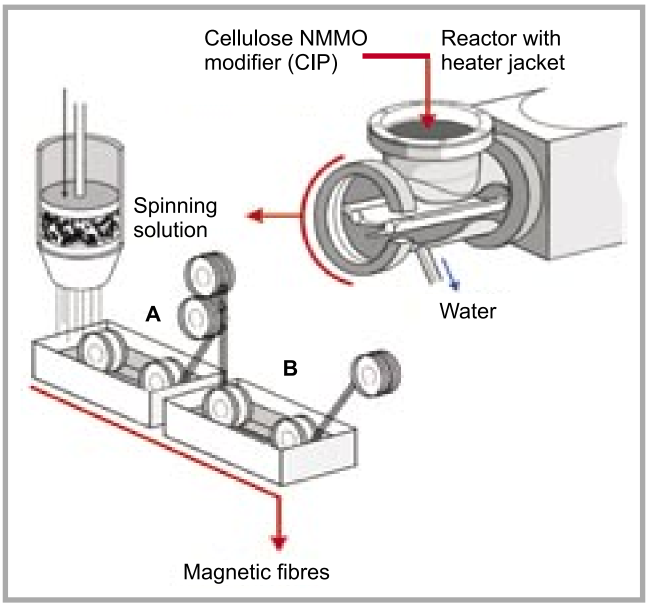
Introduction

Non-metallic fibres with magnetic properties seem to be characterised by important advantages. Unfortunately, a literature review carried out by us does not allow to state the existence of such fibres, particularly polymer fibres.

This study presents the process of manufacturing composite cellulose fibres which interact with a magnetic field and some devices which use the fibres. The fibres were spun by the dry- wet method using N-methylmorpholine-N-oxide hydrate (NMMO) as a direct solvent for cellulose. This technology is an interesting alternative to conventional methods of manufacturing cellulose fibres, as it is free from the serious drawbacks of the latter. In addition, the NMMO process is characterised by a short and simple production cycle, which is also environmentally friendly due to its closed solvent circulation. Another characteristic feature of this process is its elasticity and the ease of producing concentrated and homogeneous solutions of cellulose [1, 2].

These properties allowed us to use a fibre modification technique, incorporating a powdered modifier into the cellulose solution. This technique is one of the most effective methods of imparting new features to fibres as it guarantees stability of their properties, due to the fact that the stabile magnetic modifier is firmly integrated in the polymer matrix, and its percentage content do not changes while using the fibres. By incorporating proper compounds into the fibre-forming polymer one can, among other things, obtain improved electrical conductivity [3, 4], flame resistance [5], UV shielding and sensory properties [6].

Figure 1. Scheme and conditons of the preparation of cellulose fibres modified with magnetic powder. Dissolving conditions: maximum temp. - 110 °C, pressure - 240 hPa, dissolving time - 80 min. Spinning conditions: spinning temp. - 115 °C, coagulation bath (A) temp. - 20 °C, plasticization bath (B) temp. - 70 °C.



Experimental

The fibres under investigation were spun from cellulose solutions in NMMO hydrate by the dry-wet process. In order to prepare spinning solutions, KCBK cellulose with an alpha cellulose content of 94.1% and degree of polymerisation equal to 795 were composed.

A scheme of the preparation of cellulose fibres modified with magnetic powder together with the basic conditions of dissolving and spinning are presented in Figure 1.

The cellulose was dissolved in a IKA VISC MKD 0.6-H60 reactor equipped with heating jacket and stirrers. The effect of this process was 12% homogenous cellulose solution in the NMMO. Fibres were formed from the obtained solutions and solidified in aqueous coagulation bath prior to being put into plasticisation aqueous bath. The fibres obtained in this way were rinsed in water and dried.

Carbonyl iron powder (CIP) from BASF was used to modify the cellulose fibres.

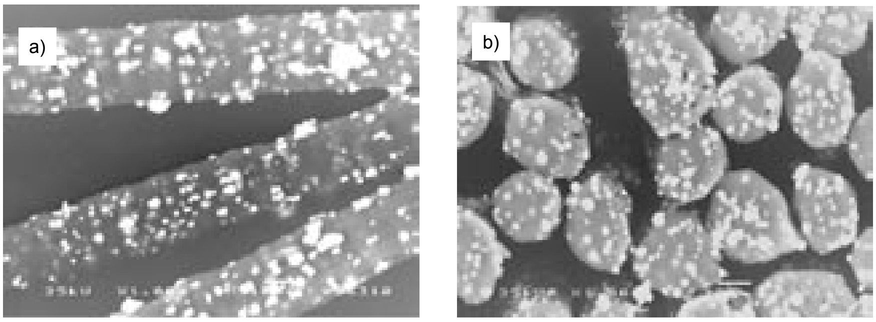


Figure 2. Longitudinal (a) and cross-section (b) view of the magnetic fibres.

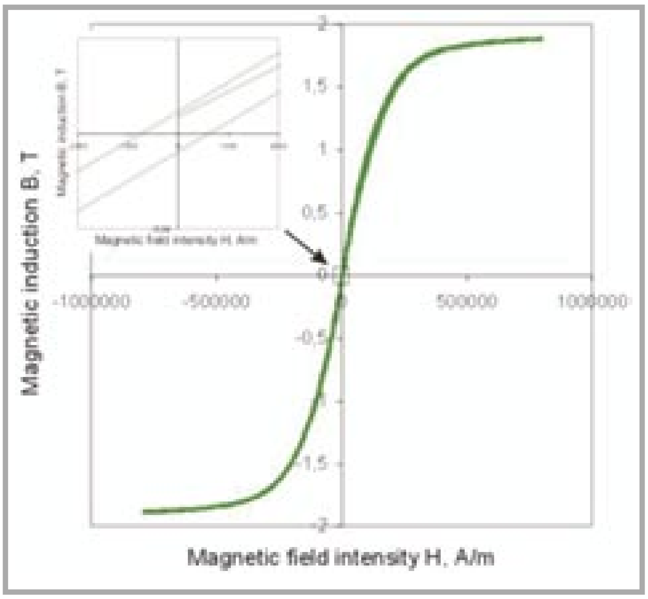


Figure 3. *Hysteresis loop for CIP.*

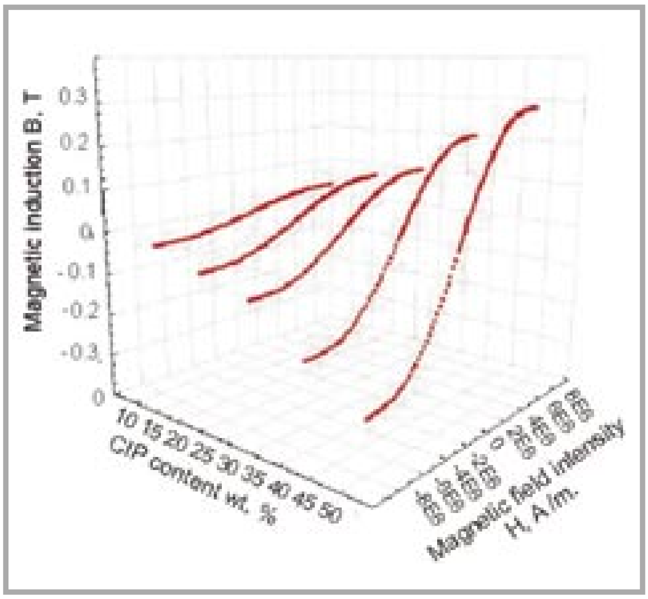


Figure 4. *Selected hysteresis loops for composite fibres.*

The term "carbonyl" refers to the starting material with carbonyl iron powders formed by the thermal decomposition of iron pentacarbonyl:

$$Fe(CO)_5 \longrightarrow Fe + 5CO$$

A ferromagnetic compound was added to the spinning solution in such quantities that its content in the final fibres would be from 10 to 50 wt.%. The fibres were spun at two spinning rates: V_1 = 50 m/min and V_2 = 70 m/min. At a solution feeding rate V_0 = 1 m/min, these spinning conditions allowed us to obtain 50-fold and 70-fold draw ratios, respectively.

The resultant fibres were tested to assess the magnetic effect obtained and their suitability for textile processing. Their magnetic properties were tested by means of a vibratory LakeShore VSM 7307 magnetometer. Fibre tenacity was measured with a Zwick Z 2.5/TN18 tensile tester.

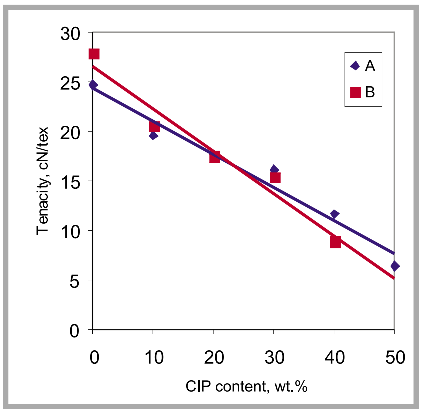


Figure 5. *Dependence of fibre tenacity on ferrite (magnetig powder) content: A – fibres spun at V_1 = 50 m/min; B – fibres spun at V_2 = 70 m/min.*

Results and discussion

The powdered ferromagnetic material was added to the mixture of cellulose, solvent and stabiliser at the beginning of cellulose dissolution during intensive stirring, which made it possible to uniformly distribute the modifier in the solution. Good component intermixing allowed us to form fibres with a uniformly distributed magnetic phase within their entire volume (Figure 2).

The incorporation of magnetical powder into the diamagnetic cellulose fibres resulted in a composite with new magnetic properties. The hysteresis loops of the composite fibres obtained and modifier are shown in Figs. 3 and 4. The magnetic properties were tested by means of a LakeShore VSM 7307 vibratory magnetometer. Fibre tenacity was measured with a Zwick Z 2.5/TN18 tensile tester.

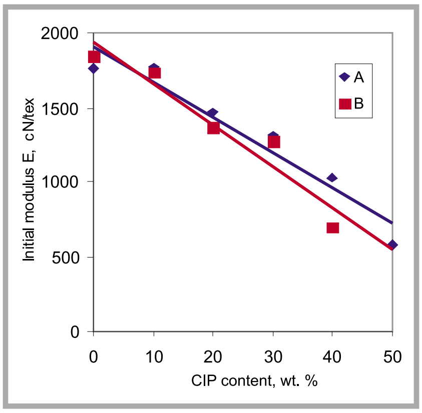


Figure 6. *Dependence of initial fibre modulus on ferrite (magnetig powder) content: A – fibres spun at V_1 = 50 m/min; B – fibres spun at V_2 = 70 m/min.*

As expected, the presence of modifier particles in fibres also affects their other properties. It was found that the strength properties of the modified fibres depends to a large extent on the magnetic modifier's content. The increase in the magnetic material content resulted in an increase in the linear density of the fibres, and unfortunately, also a decre in the tenacity and initial modulus (Figures 5 and 6).

The reduction in the strength of magnetic powder-containing fibres is caused by considerable differences in the properties of composite components. In this case, fibre deformation leads to the formation of structure discontinuity at the border between the cellulose matrix and modifier particles [7].

Macroscopic model of a textile magnetic core

The mechanical and magnetic propertioes of magnetic fibres are mapped in the general model presented in Figure 7 and the rheological model shown in Figure 8. The analysis of the phenomena takes into consideration the fiber's microstructure characterised by the polymer matrix surrounding the magnetic grains. We assume that the elementary area has the size of a magnetic grain. The model takes into account the mechanical proprieties

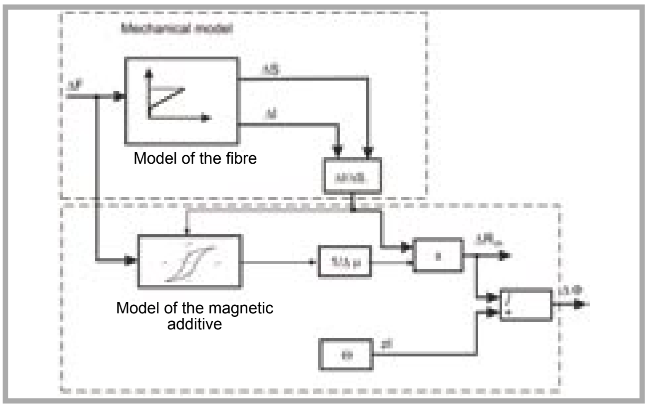


Figure 7. *Magnetic and mechanical model of the magnetic fibre; ΔF – change in force acting on the fibre; Δl – change in the fibre's length, ΔS – change in the cross-section area, Δμ - change in the magnetic permeability,* ΔR_m *- change in the fibre's reluctance [9].*

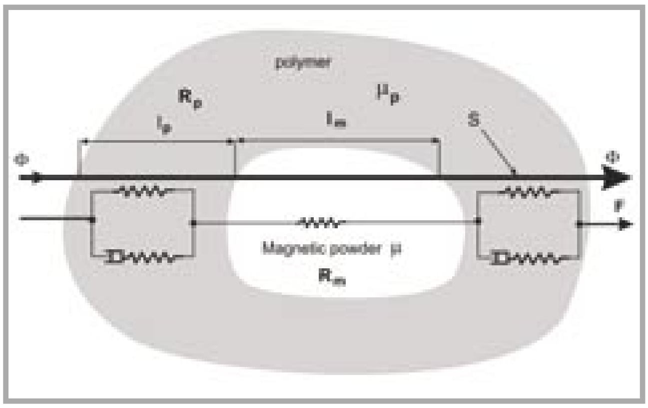


Figure 8. *Rheology model of the magnetic fibre; Φ – magnetic flux,* R_p *- polymer reluctance,* R_m *- magnetic reluctance,* l_p*,* l_m *- length of the way through the polymer, and magnetic grain, S - elementary area cross section, F - force acting on the fibre.*

of the polymer matrix and modifierr's particles. A model may represent the elementary structure of magnetic fibres, where the path of the magnetic flux Φ of the magnetic field goes through the magnetic granules and the polymer (Figure 7). This is related to the magnetic reluctance R_m and the polymer reluctance R_p, and shown by equations (1):

$$R_p = \frac{l_p}{\mu_p \cdot S}, \qquad R_m = \frac{l_m}{\mu \cdot S} \qquad (1)$$

where:

R_p – the reluctance of the polymer,
l_p – the length of the way through the polymer between the magnetic grains,
μ_p – the permeability of the polymer,
R_m – the reluctance of the magnetic grain,
l_m – the length of the way through the magnetic grain,
μ – the permeability of the magnetic grain,
S – the elementary area of the magnetic cross-section (for both curves the cross-section of the grain).

The polymer matrix differs from granulated product particles in its elastic properties. Magnetic materials are characterised by large rigidity and small elasticity. The consequence of this interpretation is the established rheology model [8].

The rheology model of the magnetic fibre includes parts of the magnetic powder and the polymer matrix. The change in the magnetic fibre causes deformation of the crystalline net of the ferromagnetic, and at the same time influences the changes in magnetic permeability Δμ. The tensions and deformations of the fibre cause a change in the geometric (length Δ*l* and cross-section area ΔS) fibre parameters. The changes in the fibre's permeability and in the geometrical dimensions together cause a change in the fibre's reluctance ΔR_m Figure 8. The change in the fibre's reluctance ΔR_m is determined by relation (2):

$$\Delta R_m = \frac{\Delta l_m}{\Delta\mu \cdot \Delta S} \qquad (2)$$

Applications of magnetic fibers

Both magnetic fibers and nonwoven made from these fibers can be used for building textronic, electromagnetic devices. An example of a practical application of magnetic textiles is a magnetic coil with textile core [8 - 10]. The coil is a basic component of textronic, electromagnetic devices. The textile core of a magnetic coil can be made from magnetic fibres or from magnetic nonwoven.

Another interesting application of magnetic nonwoven is the use as a magnetic shield, which can be a component of textronic clothes. Such nonwovens were produced by the application of the stitching method from magnetic fibres at the Department of Fibre Physics and Textile Metrology at Technical University of Łódź. The magnetic properties of fibres and nonwoven were determined and presented in the form characteristics of magnetisation. Elongation characteristics were obtained from nonwoven

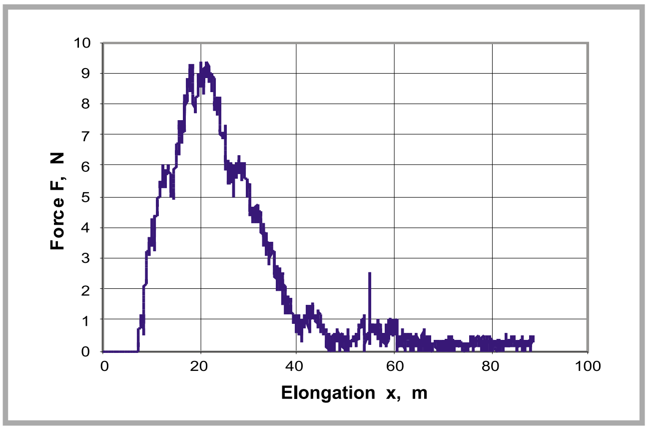


Figure 9. *Stress-string curve of a magnetic nonwoven stretched in the direction of nonwoven formation.*

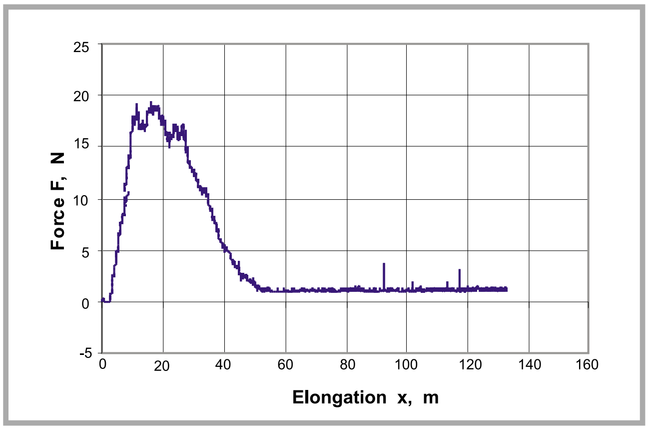


Figure 10. *Stress-string curve of the magnetic nonwoven is stretched perpendicular to the direction of nonwoven formation.*

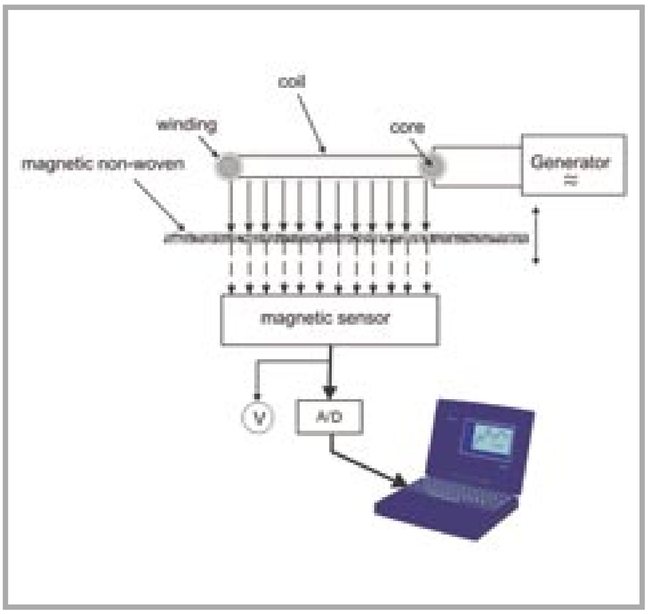


Figure 11. *Diagram of the shielding capability measuring system used in our experiment stand.*

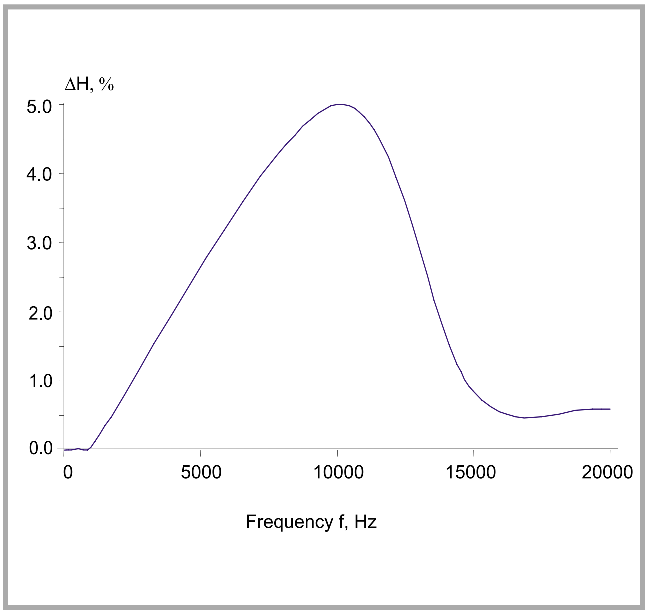


Figure 12. *Relative change in the intensity of the magnetic field with dependence on frequency (at Ho = 400 A/m).*

in two perpendicular directions, which allows for the analysis of mechanical anisotropy, see Figures 9 and 10 (see page 103) .

One direction of elongation was the same as fiber alignments during formation, whereas the second direction of elongation was perpendicular to the better.

A measurement stand was built, in order to preliminarily determine the shielding capability of the magnetic nonwoven. We limited our investigation to a preliminary estimation of the shielding capabilities due to the lack of a professional measurement stand. A scheme of measuring system is presented used in Figure 11. The measurement station consists of a power generator of sinusoidal voltage of variable frequency. The generator supplies the magnetic coil, which produces an alternating magnetic field. The magnetic field intensity sensors were covered by the magnetic nonwoven. The coil was situated on top of the sensor. The shielding proprieties were determined by changing the magnetic field intensity with dependence (3).

$$\Delta H = \frac{H_0 - H}{H_0} 100\% \qquad (3)$$

where:

H_0 – the magnetic field intensity without shielding of magnetic nonwoven,

H – the magnetic field intensity with shielding of magnetic nonwoven.

The output from the sensors was connected to a volt-meter of alternating current and to a computer by measuring card A/D.

On the basis of these measurements, we determined the characteristics of the relative change in intensity of the magnetic field in the function of the frequency of magnetic field ΔH % = F(f).

One of the characteristics is shown on Figure 12.

Conclusions

- Magnetic fibres are fibres possessing ferro-magnetic properties which can be obtained by adding ferro-magnetic powder to the cellulose matrix; they are determined by their mechanical and magnetic properties.
- The magnetic properties depend on the kind of implemented magnetic filler and the percentage content by volume in the fibre matter.
- The macroscopic magneto-mechanical and magnetic models presented, may in the future be the basis for mathematical description and simulation the procedures of magnetic fibres and textile magnetic cores.
- The increase in the efficiency of shielding the magnetic field by textiles requires application of magnetic modifiers with better magnetic properties.

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Received 15.11.2007 Reviewed 15.01.2008