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Biodegradable Paper Reinforced Poly (Vinyl Alcohol) Composites for Packaging

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Abstract: **Poly (vinyl alcohol) composites reinforced with three kinds of papers which differ by voids content were investigated. Paper fibre length distribution was established as well as the structure of cross sections of paper and composites were studied by scanning electron microscope. The denser is a paper, the more loosens its structure after immersion in water and the more decreases its tensile strength after soaking and subsequent drying. The less dense is a paper, the more completely it was filled by polymer and the greater is an increase of strength-deformation characteristics of the composite. The increase of these characteristics is grater in the direction perpendicular to the fiber orientation route. The air permeability of composites and untreated paper as well as character their biodegradation were investigated.**

***Keywords*: paper, poly (vinyl alcohol), biodegradable composite, strength-deformation characteristics, structure, air permeability, biodegradation**

I INTRODUCTION

There is a growing worldwide interest to increase the use of renewable resources in commodity plastic products in order to diminish the waste associated to their use, particularly in packaging applications. The utilization of biodegradable plastics and resources is one of the many strategies to minimise the environmental impact of petroleum-based plastics [1].

As a result, interest in the use of naturally degradable and/or biodegradable polymers for plastic manufacturers has grown. Efforts have been made to develop environmentally compatible plastic products by incorporating renewable polymers as an alternative to petroleum-derived chemicals. The renewable polymers are relatively cheap, environmentally friendly, and also naturally biodegradable. PVA is well suited for blends with natural polymers since it is highly polar and can be processed in water solutions [2].

The key to successful packaging is the selection of proper material and package design that best satisfy specific product demands [3]. In order to tailor the properties and reduce material costs, it is often desirable to combine bioplastic materials with other, ideally, more inexpensive substances, such as natural fibres (e.g. cellulose) [1].

One of the most known cellulose products is paper - a pliable material used for writing, packaging, hygiene and a variety of specialized purposes. The cellulose fibre is strong and has a great bonding capacity of its own. The properties of pulp fibres determine many of the characteristics of the final paper. For instance, long fibres give strength, but short – better formation and more even surface. Paper may also contain various additives used to improve the finished paper itself or aid in the process of papermaking: dyes, sizing agents, strength aids, fillers, drainage aids and retention aids. The quality of the different components determines the quality of the paper and also the runnability on the paper machine [4,5].

The aim of this paper is to prepare and characterise paper/poly (vinyl alcohol) (PVA) composites, where paper formally acts as a reinforcing component for polymer matrix. Structural and mechanical characteristics of broad range of papers potentially to be used as polymer matrix reinforcement have already been examined and described in [6]. Three distinctive types of papers which differ by voids content (volume fraction: 0.40, 0.56 and 0.70, respectively) were selected for development of composites.

II MATERIALS AND METHODS

Partly crystalline water soluble PVA (GOST 10779-78) was used. Its molecular weight was 133 kDa, density 1.28 g/cm^3, melting temperature 226°C, glass transition temperature 77°C and content of acetate groups 0.98 wt%.

The polymer was laid on the paper base from polymer water solution by hand applicator. Four different PVA concentrations (7, 10, 12 and 15 wt %) and two applicator gap heights (0.30 and 0.50 mm) were used to vary the polymer content φ_{pol} in composite.

The most important macrostructure characteristics of paper and composites are thickness h and voids content φ_{voids}. There are some characteristics to be established for further calculations: density of PVA d_{pol} = 1.28 g/cm^3 and density of cellulose d_{cel} = 1.52 g/cm^3. Weight m_{S} of samples with 100 cm^2 area S was determined on “Precisa XT 220A” balance. The thickness h was measured with “Mitutoyo” flat digital micrometer.

The volume V, density d, grammage m_{S}, volume of voids V_{voids} and voids volume fraction φ_{voids} was calculated: $V_{\text{pap}} = S_{\text{pap}} \cdot h_{\text{pap}}$; $d_{\text{pap}} = m_{\text{pap}} / V_{\text{pap}}$; $m_{\text{Spap}} = m_{\text{pap}} / S_{\text{pap}}$. In the same way respective V, d and m_{S} of composite were calculated.

Assuming that: $V_{\text{cel}} = m_{\text{pap}} / d_{\text{cel}}$; $V_{\text{pol}} = m_{\text{pol}} / d_{\text{pol}}$; $V_{\text{voidsP}} = V_{\text{pap}} - V_{\text{cel}}$ and $V_{\text{voidsC}} = V_{\text{comp}} - V_{\text{pol}} - V_{\text{cel}}$ it is possible to determine:

$$\varphi_{\text{voidsP}} = V_{\text{voidsP}} / V_{\text{pap}} \text{ and } \varphi_{\text{voidsC}} = V_{\text{voidsC}} / V_{\text{comp}}, \qquad (1)$$

where indexes designate following: pap – paper, pol – polymer (PVA), comp – composite, cel – cellulose, voidsP – voids in polymer, voidsC - voids in composite.

It was assumed for calculations that the only constituent of paper is cellulose ignoring other possible constituents of negligible quantity.

Lorentzen & Wettre "Fiber Tester" Code 912 with incorporated analyser instrument and a computer program for estimation of cellulose fibre dimensions of paper was used. About 0.2 g of paper fibres disintegrated in 200 ml of distilled water was necessary to perform the test and establish fibre length and width as well as their size distribution.

The tensile properties of paper and composites were determined by "Zwick/Roell" universal testing device. For tensile experiments samples according to standard LVS EN ISO 1924-2 in machine and cross directions (MD and CD, respectively) were prepared and tested. Tensile strength (σ_B), elongation at break (ε_B) and elastic (Young) modulus (E) were calculated by use of supporting computer program *testXpert*®.

To evaluate the water sorption of paper, 2 x 2 cm samples were prepared, immersed in distilled water and subsequently weighted until constant weight was reached to determine sorption dynamics. The percental mass changes w were calculated according to equation

$$w = (m_2 - m_1)/m_1 \cdot 100\%, \qquad (2)$$

where m_2 – initial sample weight, g,
m_1 – sample weight after exposing in water, g.

Biodegradability was assessed as mass loss (z) in microbiologically active garden soil. Sample of size 3 x 3 cm was inserted in Petri dish with humidified soil to imitate environment conditions and exposed to 25°C temperature. After set time samples were washed from soil, dried and weighted.

$$z = (m_0 - m)/m_0 \cdot 100\%, \qquad (3)$$

where m_0 – initial sample weight, g,
m – sample weight after exposing in soil, g.

For microscopic studies of structure of paper and composite, samples were cooled in liquid nitrogen and fractured by bending. Brittle fracture cross sections were covered with gold (Emitech, K550X) and investigated by Tescan, Mira/LMU Shottky scanning electron microscope (SEM) at the 600 x and 1000 x magnification and voltage of 7 and 15 kV.

Air permeability was estimated by measuring the air flow through a defined area A = 5 cm^2 under 2 kPa pressure difference.

III RESULTS AND DISCUSSION

The essential structure characteristics of examined papers are demonstrated in Table 1 but strength - deformation characteristics in Table 2.

TABLE 1
CHARACTERISTICS OF PAPER STRUCTURE

Characteristic	Designation	Paper designation		
		FL 70	KP 90	ML 150
Thickness, μm	h	158	136	165
Conventional density, g/cm^3	d	0.46	0.67	0.91
Voids volume fraction	φ_{voids}	0.70	0.56	0.40
Volume fraction of absorbed water	φ_{H2O}	0.82	0.74	0.66
Gas permeability (Δp = 2 kPa), l/min	q	8.30	1.15	0.37

TABLE 2
STRENGTH – DEFORMATION CHARACTERISTICS OF PAPERS

Characteristic	Designation	Paper designation		
		FL 70	KP 90	ML 150
Ultimate tensile strength, MPa	σ_B			
- machine direction (MD)	$\sigma_{B\,MD}$	17.7	53.9	53.5
- cross direction (CD)	$\sigma_{B\,CD}$	8.0	21.1	22.7
MD/CD	$\sigma_{B\,MD}/\sigma_{B\,CD}$	2.2	2.5	2.4
Elongation at break, %	ε_B			
- machine direction (MD)	$\varepsilon_{B\,MD}$	1.3	2.3	2.4
- cross direction (CD)	$\varepsilon_{B\,CD}$	1.7	4.8	4.3
CD/MD	$\varepsilon_{B\,CD}/\varepsilon_{B\,MD}$	1.3	2.1	1.8
Tensile elastic modulus, GPa	E			
- machine direction (MD)	E_{MD}	2.3	5.0	4.8
- cross direction (CD)	E_{CD}	1.0	1.9	2.0
MD/CD	E_{MD}/E_{CD}	2.3	2.6	2.4

Tensile strength of the less dense paper FL 70 is the smallest both in machine and cross direction. However, as we have already observed in [6], there is no strict correlation between density and tensile strength and elongation at break.

Cellulose fibre length distribution (Fig.1) for papers whose σ_B values are similar (KP 90 and ML 150) is almost equivalent. Although amount of cellulose fibres in paper FL 70 within range 1.5 – 3.0 mm is extended but for other two papers dominate fibres with length in smaller interval 0.5 to 1.5 mm, there was observed three times lesser strength for FL 70 while its density is only two times lesser.

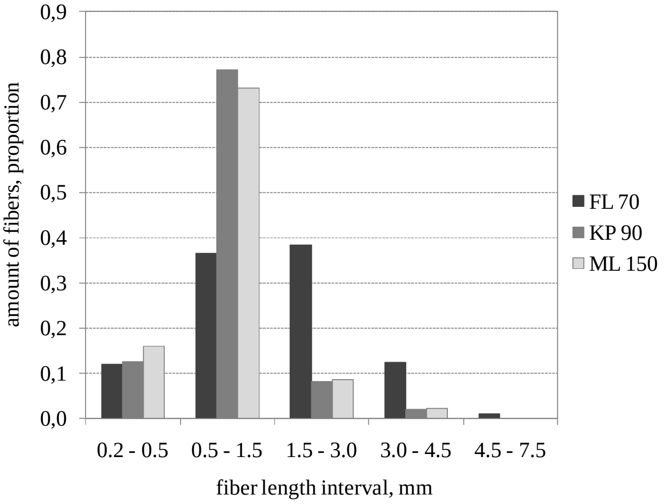
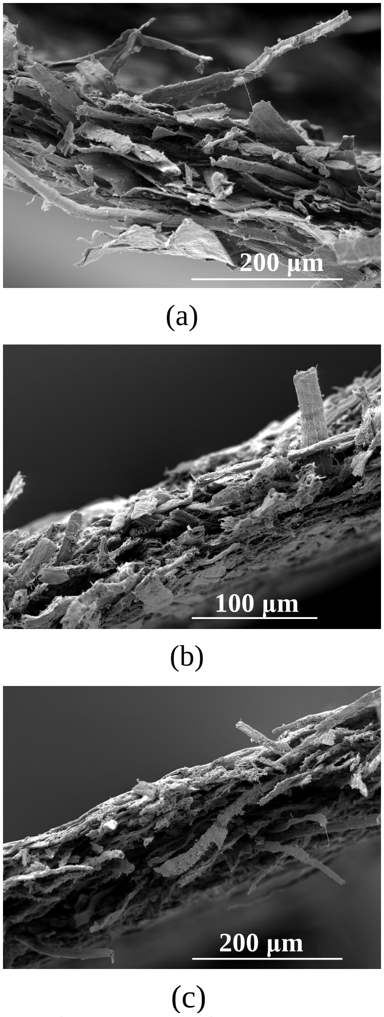


Fig. 1. Distribution of cellulose fibre length

SEM images (Fig.2) also gives no explanation about almost equivalent tensile properties of KP 90 and ML 150. At the same time density of both reinforcements is considerably different. Obviously the strength characteristics of paper are determined by a complex: density, cellulose fibre length distribution as well as bonding between fibres provided by various additives used in paper manufacturing.

No additives can be seen in SEM images of FL 70, whilst for KP 90 and ML 150 some additive inclusions were observed.



(a)

(b)

(c)

Fig. 2. SEM images of cross sections of untreated papers: (a) FL 70, (b) KP 90, (c) ML 150

TABLE 3

CHARACTERISTICS OF PAPER WATER ABSORPTION

Paper designation	φ_{voids}	φ_{H2O}	φ_{H2O} - φ_{voids}	(φ_{H2O} - φ_{voids})/ φ_{H2O}
FL 70	0.70	0.82	0.12	0.15
KP90	0.56	0.74	0.18	0.24
ML150	0.40	0.66	0.26	0.39

TABLE 4

THE INFLUENCE OF WATER ON PAPER TENSILE STRENGTH

Paper designation	φ_{voids}	σ_B, MPa	σ_B^{H2O}, MPa	$(\sigma_B - \sigma_B^{H2O})/\sigma_B$
FL 70	0.70	17.6	15.7	0.11
KP 90	0.56	53.9	42.6	0.21
ML 150	0.40	53.5	37.5	0.30

Since composite materials are developed by treating paper with PVA water solution, paper water sorption ability was of special interest. 90 - 95 % of absorbed water equilibrium values all kinds of papers reach in first 5 minutes after immersion in water (about 2 % of time necessary to achieve equilibrium). Samples absorb equilibrium amount of water in approximately 240 minutes.

When paper voids fills with water, its structure loosens. Consequently the equilibrium volume fraction of absorbed water φ_{H2O} is greater than voids fraction φ_{voids} for all studied paper reinforcements. Table 3 demonstrates: the less dense is paper structure (higher φ_{voids} value), the lesser loosens the paper structure – difference $\varphi_{H2O} - \varphi_{voids}$ is smaller.

Besides, the loosening of paper structure during water sorption is not completely reversible, and that influences also paper strength properties after drying. Initial tensile strength σ_B of all papers is higher than that after soaking and subsequent drying σ_B^{H2O} (Table 4).

Relative decrease of paper strength: $(\sigma_B - \sigma_B^{H2O})/\sigma_B$ as well as relative increase of voids volume fraction $(\varphi_{H2O} - \varphi_{voids})/\varphi_{H2O}$ decline with rising of φ_{voids} value (Fig.3).

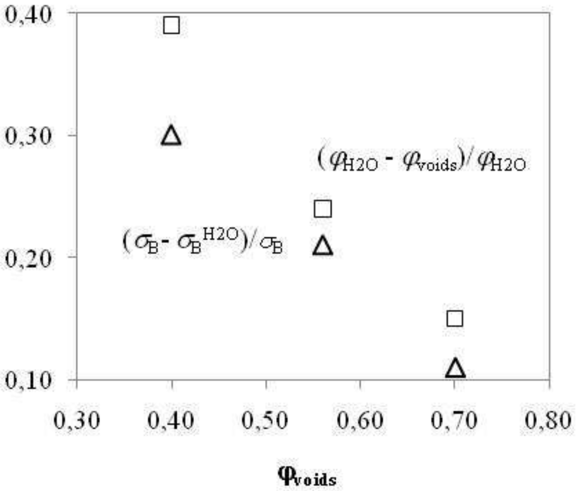


Fig. 3. Relative decrease of paper strength (triangles) and relative increase of voids volume fraction (squares) for papers with different voids content φ_{voids}

All established facts brings to the opinion that less dense paper FL 70 is most suitable for creation of reinforced PVA composite materials.

Alteration of voids volume fraction in composite φ_{voidsC} with increase of volume fraction of incorporated polymer φ_{pol} should conform to following expression:

$$\varphi_{voidsC} = \varphi_{voidsP} - \alpha\varphi_{pol}\,, \qquad (4)$$

where α – factor, that characterizes volume fraction of polymer that really has filled paper voids.

$$\alpha = (\varphi_{voidsP} - \varphi_{voidsC})/\varphi_{pol}.$$

If all applied polymer fills voids (while $\varphi_{voidsP} \geq \varphi_{pol}$), $\alpha = 1$.

Changes of voids content in composite φ_{voidsC} with φ_{pol} are shown in Fig.4, respective changes of relative voids content $\varphi_{voidsC}/\varphi_{voidsP}$ – in Fig.5. Ideal filling ($\alpha = 1$) in Fig.4 and Fig.5 are represented by dashed lines.

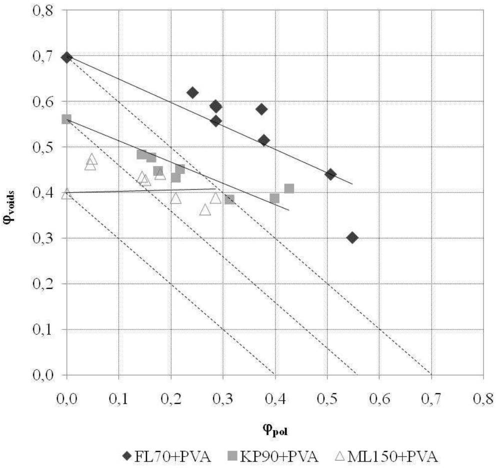


Fig.4. Change of experimental φ_{voidsC} values with φ_{pol}

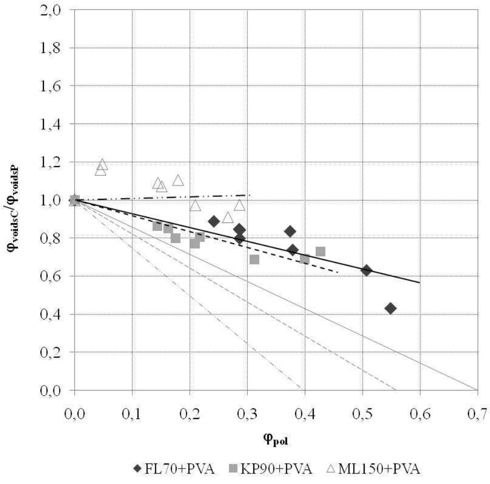


Fig. 5. Change of relative voids content $\varphi_{voidsC}/\varphi_{voidsP}$ with φ_{pol}

TABLE 5

FACTORS CHARACTERIZING FILLING OF PAPER BY POLYMER IN COMPOSITES

Paper designation	φ_{voidsP}	α		α/φ_{voidsP}		β		
		complete filling	experi-mental	complete filling	experi-mental	complete filling	experi-mental	no filling
ML150	0.40	1	- 0.03	2.50	- 0.08	0	1.1	0.60
KP90	0.56	1	0.52	1.79	0.83	0	0.14	0.44
FL70	0.70	1	0.57	1.42	0.73	0	≈ 0	0.30

Figures 4 and 5 together with Table 5 data obviously demonstrate that only a part of polymer fills paper voids ($\alpha < 0.57$). The higher is voids content of paper φ_{voidsP}, the greater is α value.

Surprisingly little part of applied polymer penetrates into paper ML 150 ($\varphi_{\text{voids}} = 0.40$). At low φ_{pol} values φ_{voidsC} is even a slightly higher then φ_{voidsP}.

Certain information concerning composite structure presents measurements of its thickness h_{comp}. In idealized case, when all amount of applied polymer flows into paper voids, $h_{\text{comp}} = h_{\text{pap}}$ and $h_{\text{comp}}/h_{\text{pap}} = 1$. On the other hand, if polymer do not flows into paper voids at all and forms a separate layer, the thickness of this layer can be calculated according to the following equation:

$$h_{pol} = \frac{\varphi_{pol} h_{pap} \left(1-\varphi_{voidsP}\right)}{1-\varphi_{pol}} \tag{5}$$

The thickness of composite in this case:

$$h_{komp} = h_{pap} + h_{pol} = h_{pap} + h_{pap}(1-\varphi_{voidsP})\frac{\varphi_{pol}}{1-\varphi_{pol}}, \tag{6}$$

and its relative value can be estimated subsequently:

$$\frac{h_{komp}}{h_{pap}} = 1 + (1-\varphi_{voidsP})\frac{\varphi_{pol}}{1-\varphi_{pol}}. \tag{7}$$

In common case relative value of composite thickness is described by equation:

$$\frac{h_{komp}}{h_{pap}} = 1 + \beta\frac{\varphi_{pol}}{1-\varphi_{pol}}. \tag{8}$$

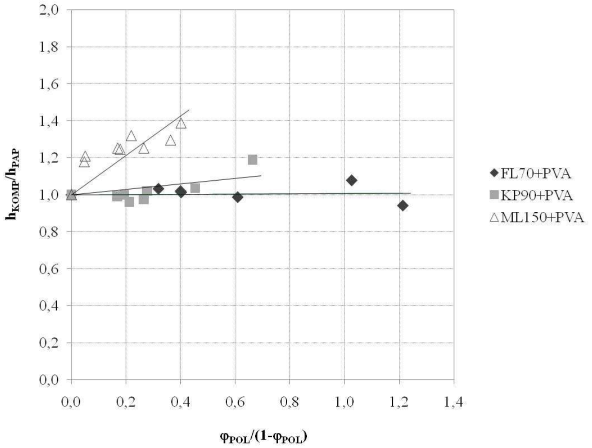


Fig. 6. Interconnection between relative composite thickness and polymer amount in composite

Figure 6 and Table 5 give evidence that relationship between $\dfrac{h_{comp}}{h_{pap}}$ and $\dfrac{\varphi_{pol}}{1-\varphi_{pol}}$ for less dense paper FL 70 complies with complete filling of voids ($\beta \approx 0$).

Equations (4-8) describe situation when structure of paper does not transform in a course of penetration, however the experimental results obviously confirm that some changes occur (see Table 3 and Fig.3).

SEM images show that distribution of polymer inside the paper structure is not uniform. Micrographs of untreated paper FL 70 (Fig.3(a)) show its loose and porous structure, whereas Fig.7(a) disclose that after application of PVA solution its structure arranges and gets more compact. As a result, the thickness of composite does not grow; it even diminishes a little.

The change of paper structure more likely is a reason why equation (4) $\varphi_{\text{voidsC}}(\varphi_{\text{pol}})$ affirms that voids of paper FL 70 have filled partly: $\alpha = 0.57$ (Table 5), whilst equation (6) $h_{\text{comp}}(\varphi_{\text{pol}})$ indicates complete filling: $\beta \approx 0$ (Table 5).

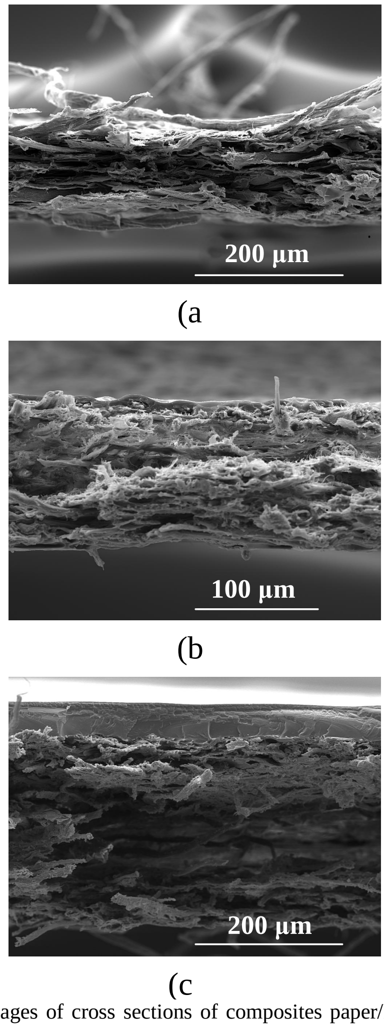


Fig. 7. SEM images of cross sections of composites paper/PVA: (a) FL 70, $\varphi_{pol} = 0.24$; (b) KP 90, $\varphi_{pol} = 0.21$; (c) ML 150, $\varphi_{pol} = 0.28$.

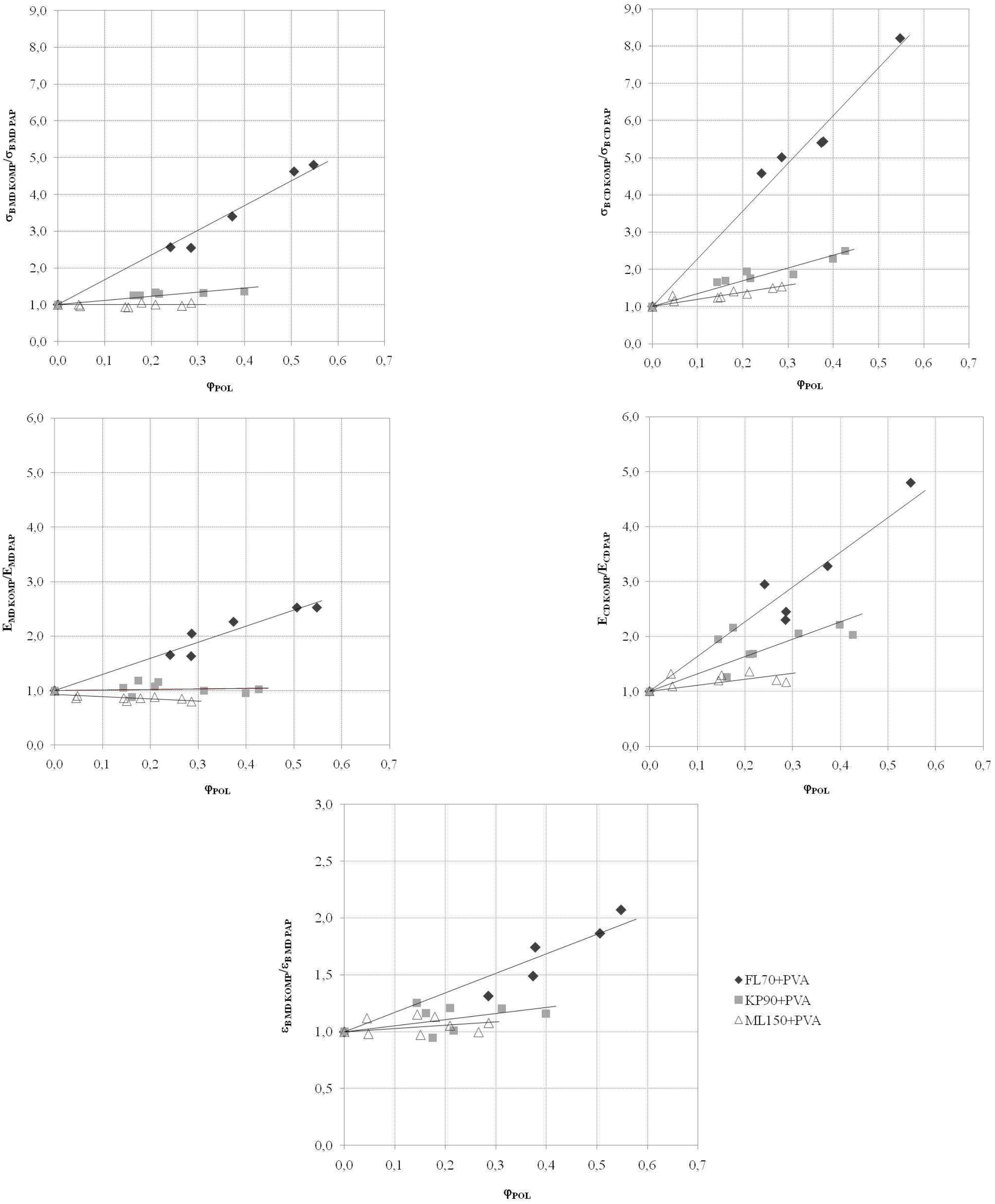


Fig. 8. Change of relative values of strength – deformation characteristics R_{comp}/R_{pap} with polymer content φ_{pol} in the composite: (a) tensile strength in MD; (b) tensile strength in CD; (c) tensile elastic modulus in MD; (d) tensile elastic modulus in CD; (e) elongation at break in MD

Even a small amount of applied polymer (φ_{pol} = 0.21 vol. fraction) forms thin 3 -5 μm layer on paper KP 90 surface, however the thickness of composite is similar to untreated paper. Comparing structure of untreated KP 90 with composite (Fig.7(b)), polymer inside the paper is visible, and the structure seems more dense. According to measurements and calculations, the composite has filled partly: $\alpha = 0.52$; $\beta = 0.14$ (Table 5).

For paper ML 150 $\alpha \approx 0$ and $\beta = 1.1$ (Table 5). Besides, value of β is even greater than calculated value of this coefficient for a case if no filling occurs ($\beta = 0.60$). Due to great density of ML 150 ($d = 0.91$ g/cm^3), there are some restrictions for polymer penetration into the paper structure. Remarkable (30 - 40 μm) polymer layer has developed on surface (Fig.7(c)). Besides, paper structure itself has loosened, and its thickness has considerably increased.

The change of relative values R_{comp}/R_{pap} of most essential strength-deformation characteristics (where R_{comp} and R_{pap} are values of certain characteristic for composite and paper, respectively) with polymer content in the composite represents Fig. 8.

It seems acceptable to approximate the dependence of all relative values on polymer content in composite by linear equation:

$$\frac{R_{comp}}{R_{pap}} = 1 + \lambda \varphi_{pol} \qquad (9)$$

Value of the empirical factor λ indicates an extent how the actual parameter grows with increase of polymer content (Table 6). The highest λ values possess FL 70 - the less dense reinforcement (greatest $\varphi_{\mathrm{voidsP}}$ value) which shows the highest level of filling with polymer (greatest α value).

Paper is an anisotropic material. The orientation of cellulose fibres mostly along machine direction (MD) can be observed easily (Fig.9). As can be seen from Tables 2 and 7 the tensile elastic modulus as well as tensile strength in MD is more than twice of cross direction (CD) value.

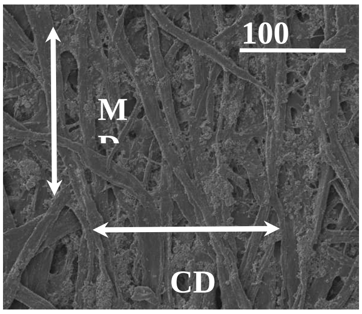


Fig. 9. Orientation of paper cellulose fibres

The σ_B values in cross direction with increase of polymer content grow more efficiently than in MD (λ factor is higher). This appoints that polymer matrix increases bonding among cellulose fibres what is essential for strength properties in cross direction. Table 7 demonstrates the normalized values of tensile strength σ_B of composites at $\varphi_{\mathrm{pol}} = 0.3$ and 0.5 (italic). The greatest increase of strength in comparison with untreated paper shows the less dense paper (in MD more than 4 times, but in CD almost 8 times). Consequently, the relation MD/CD of tensile strength decreases from 2.2 for untreated FL 70 to 1.3 for composite.

Experimental measurements of the gas (air) permeability (q) of paper and its composites (Fig.10(a)) show considerable drop of permeability with growth of polymer volume fraction φ_{pol} in composite. In addition, the greatest decrease comparing to permeability of untreated paper was observed for less dense paper: more than 30 times at $\varphi_{\mathrm{pol}} \approx 0.5$ (Fig.10(c)). As predicted, there is a correlation between air permeability and voids content (Fig.10(b)), what means that composites contain no closed pores (voids).

The preliminary experimental data on biodegradation are promising. The mass loss in soil of untreated papers is huge and there is only a little difference among examined papers. In first two weeks papers lose about 40 % of their initial mass but after 5 – 6 weeks papers are completely disintegrated. Considering data of mass loss, composite with little polymer content ($\varphi_{\mathrm{pol}} < 0.2$) disintegrates faster than paper. It was established that after two weeks there remained only about 30 % of initial mass. After four weeks composites are totally disintegrated.

TABLE 6

VALUES OF FACTOR λ

Paper designation	$\varphi_{\mathrm{voidsP}}$	λ					
		E		σ_B		ε_B	
		MD	CD	MD	CD	CD	MD
ML150	0.40	- 0.7	1.1	0.3	1.9	6.3	0.3
KP90	0.56	0.1	3.1	0.5	3.5	7.0	0.5
FL70	0.70	3.0	6.3	1.7	12.8	7.5	1.7

TABLE 7

COMPARISON OF TENSILE STRENGTH σ_B IN MACHINE DIRECTION AND CROSS DIRECTION OF PAPERS AND COMPOSITES

Paper desig-nation	Paper			Composite				
	$\sigma_{B\ MD\ pap}$	$\sigma_{B\ CD\ pap}$	$\sigma_{B\ MD\ pap}$ / $\sigma_{B\ CD\ pap}$	$\sigma_{B\ MD\ comp}$	$\sigma_{B\ MD\ comp}$ / $\sigma_{B\ MD\ pap}$	$\sigma_{B\ CD\ comp}$	$\sigma_{B\ CD\ comp}$ / $\sigma_{B\ CD\ pap}$	$\sigma_{B\ MD\ comp}$ / $\sigma_{B\ CD\ comp}$
FL 70	17.7	8.0	2.2	53.1	3.0	39.2	4.9	1.4
				76.1	*4.3*	*60.0*	*7.5*	*1.3*
KP 90	53.9	21.1	2.5	70.1	1.3	42.2	2.0	1.7
				80.1	*1.5*	*59.0*	*2.8*	*1.4*
ML 150	53.5	22.7	2.4	53.5	1.0	36.3	1.6	1.5
				53.5	*1.0*	*45.4*	*2.0*	*1.2*

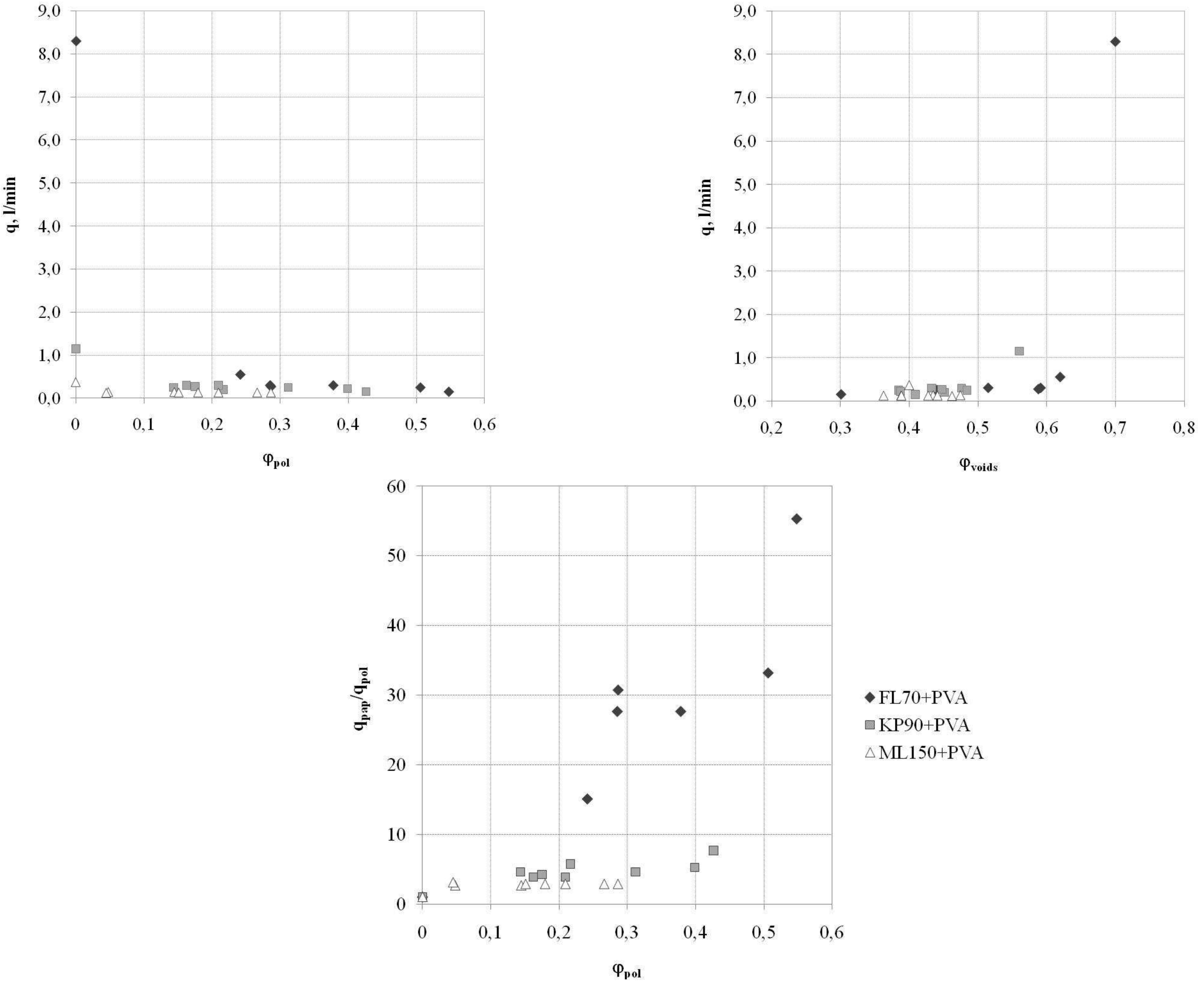


Fig. 10. (a) Influence of polymer content on air permeability of paper and composites; (b) influence of voids content on air permeability of paper and composites; (c) changes of air permeability after treatment with polymer (all at 2 kPa pressure difference)

IV CONCLUSIONS

Tensile strength of papers with similar fibre length distribution is similar, however greater amount of longer fibres in less dense paper FL 70 alone do not provide higher strength. Strength characteristics of paper are determined by a complex: density, cellulose fibre length distribution as well as bonding between fibres.

All investigated papers absorb water very rapidly: 90 - 95 % of absorbed water equilibrium value is reached in first 5 minutes after immersion in water (about 2 % of time necessary to achieve equilibrium). Volume fraction of absorbed water at equilibrium is greater than volume fraction of voids in dry paper. The denser is structure of paper, the more loosens its structure during sorption process and the more diminishes their tensile strength after subsequent drying of samples.

Experimental results and respective calculations of characteristics of composites approve that with increase of polymer content in composite the voids content decreases. Voids are not filled completely; a part of unfilled pores remains. The less dense is paper, the greater fraction of voids is filled by polymer. SEM images evidence, that structure of systems paper/PVA is more compact. No separate polymer layer can be observed on more porous paper, although for other two papers compact polymer layer can be seen – thicker for denser paper.

The dependence of relative values of most essential strength-deformation characteristics (tensile strength and elastic modulus) on polymer content in composite can be approximated by linear equation: $R_{comp}/R_{pap} = 1 + \lambda\, \varphi_{pol}$ (R_{comp} and R_{pap} - values of certain characteristic for composite and paper, respectively). Factor λ indicates an extent how the actual parameter grows with increase of polymer content. The highest λ values possess the less dense reinforcement which shows the highest level of filling with polymer. For all composites the properties in the direction across the route of cellulose fibre orientation are enhanced more than along fibre orientation. It appoints to increase of bonding between cellulose fibres in the presence of polymer.

All established facts let conclude that less dense paper (FL 70) is most suitable to create reinforced PVA composites.

The air permeability of composites is considerably lower than that of untreated paper. The greater is voids content in paper, the more it fills with polymer, and consequently the drop of air permeability in comparison with untreated paper is greater.

The data on biodegradation show very fast disintegration of both paper and composite. Paper and composite with small polymer content totally disintegrate approximately after a month. Composites with higher polymer amount in the same period have lost about 80% of their initial weight.

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Dace Čerpakovska, Māŗtiņš Kalniņš, Velta Tupureina, Anda Dzene. Ar papīru stiegroti biodegradabli polivinilspirta kompozīti iepakojumam.

Pētīti stiegroti polivinilspirta (PVS) kompozīti, izmantojot par stiegrojošo materiālu trīs dažādu veidu papīru paraugus ar atšķirīgu tukšumu tilpuma daļu (0,40 – 0,70) un, kā sekas, ar atšķirīgu stiepes elastības moduli (2,3 – 5,0 GPa), stiprības robežspriegumu stiepē (17,7 – 53,9 MPa), trūkšanas relatīvo pagarinājumu (1,3 – 2,4). Noskaidrots papīru veidojošo celulozes šķiedru izmēru sadalījums: visiem papīru veidiem dominējošās (līdz 80%) ir šķiedras ar garumu intervālā no 0,5 līdz 1,5 mm. Ar skenējošās elektronu mikroskopijas palīdzību pētīta papīra un kompozītu struktūra šķērsgriezumā (trauslais lauzums pēc izturēšanas šķidrā slāpeklī). Jo blīvāks papīrs, jo vairāk uzirdinās tā struktūra ūdens absorbcijas procesā un lielākā mērā neatgriezeniski samazinās tā stiepes stiprība pēc piesūcināšanas ar ūdeni un sekojošas žāvēšanas. Jo lielāka ir tukšuma tilpuma daļa papīra struktūrā, jo pilnīgāk notiek tā struktūras aizpildīšanās ar polimēru un jo lielākā mērā pieaug kompozītu stiepes stiprības-deformācijas raksturlielumi. Eksperimentālās relatīvās stiepes elastības moduļa, stiepes stiprības robežsprieguma un trūkšanas pagarinājuma vērtību atkarību no polimēra tilpuma daļas kompozītā pirmajā tuvinājumā iespējams aprakstīt ar lineāru vienādojumu. Pētītie papīru paraugi raksturojas ar būtisku struktūras un stiprības-deformācijas rādītāju anizotropiju. Lielāks elastības moduļa, trūkšanas pagarinājuma un stiprības robežsprieguma pieaugums ir paraugiem virzienā, kas perpendikulārs stiegrojošo šķiedru orientācijas virzienam. Kompozītu gaisa caurlaidība būtiski samazinās, palielinoties polimēra saturam kompozītā. Lielākais gaisa caurlaidības kritums novērojams mazāk blīviem papīriem. Pētīta papīru un kompozītu dezintegrēšanās bioloģiski sadaloties augsnē. Izejot no masas zudumu mērījumiem, kompozīti ar nelielu polimēra saturu (tilpuma daļa < 0.2) dezintegrējas ātrāk, salīdzinot ar atbilstošo papīra veidu.

Даце Черпаковска, Мартыньш Калныньш, Велта Тупурейна, Анда Дзене. Армированные бумагой биоразлагающиеся композиты на основе поливинилового спирта для упаковки.

Исследованы армированные композиты на основе поливинилового спирта. В качестве армирующего материала использовались три вида бумаги, отличающиеся содержанием объемной доли пустот (0,40 – 0,70) и, как следствие, различающиеся значениями модуля эластичности при растяжении (2,3 – 5,0 ГПа), предела прочности при растяжении (17,7 – 53,9 МПа) и относительной деформации при разрыве (1.3 – 2.4). Выяснено распределение по размерам образующих бумагу волокон целлюлозы: для всех видов бумаги преобладают (до 80 %) волокна длиной от 0,5 до 1,5 мм. Методом сканирующей электронной микроскопии исследовалась структура поперечных сечений бумаг и композитов (хрупкий излом после выдержки в жидком азоте). Чем плотнее бумага, тем в большей степени разрыхляется ее структура и тем существеннее необратимо снижается ее прочность при растяжении после насыщения водой и последующей сушки. Чем больше объемная доля пустот в структуре бумаги, тем полнее происходит заполнение ее структуры полимером и тем в большей степени возрастают значения деформационно-прочностных характеристик композитов. Зависимости экспериментальных относительных значений модуля эластичности, предела прочности при растяжении и удлиннения при разрыве от объемной доли полимера в композите в первом приближении можно аппроксимировать линейным уравнением. Исследованные образцы бумаги характеризуются существенной анизотропией структуры и деформационно-прочностных характеристик. Больший прирост значений модуля эластичности, удлиннения при разрыве и предела прочности наблюдался для образцов испытанных в направлении перпендикулярном направлению преимущественной ориентации армирующих волокон. Воздухопроницаемость композитов существенно снижается с ростом содержания полимера в композите. Большее снижение воздухопроницаемости наблюдается для образцов менее плотной бумаги. Исследовалась дезинтеграция образцов бумаги и композитов в процессе биологического разложения в почве. Исходя из измерений потерь массы, композиты с небольшим содержанием полимера (< 0.2 объемных долей) дезинтегрируются быстрее, в сравнении с образцами бумаги.