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New Generation of Knitted Fabrics from Degradable Synthetic Yarns

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Abstract
The possibility of using yarns of biodegradable polyester raw materials creates a new area of research works in knitted fabric technology. Because of the raw material characteristics and different properties of non-woven biodegradable materials, the knitted fabrics under investigation constitute a new generation of technological solutions. The research results presented above concern technological solutions for knitwear and dressing products made of a new generation of multifilament yarns of polylactide (PLA) and poly(glycolide-co-lactide) (PGLA). Due to the technological works a knitting technique was applied for the construction of the fabrics. Structural solutions for the fabrics were developed for medical dressings and hygienic dressing bands. The materials have biodegradable properties confirmed experimentally. The chemical purity of the materials was determined on the basis of medical product criteria.

Key words: *aliphatic polyester, multifilament yarns, course knitting, medical dressing materials.*

Introduction

The technology of knitted fabrics of biodegradable copolyester yarns constitutes a relatively new field of research works [1 - 3]. Currently there are known warp-knitted fabrics for clinical application made of conventional synthetic yarns such as polyester, polypropylene or polyamide yarns. The areas of their clinical use include, first of all, cardiosurgery, osteoarticular and vascular surgery, orthopedics and ophthalmology. These fabrics also find application in the therapy of urologic and gynecologic chronic illnesses, compress-therapy, the treatment of post-burn scars and as components of artificial skin and dressing materials [4, 5].

Biodegradable synthetic polymers are commonly known for clinical implantation application as suture materials and bone binders. The most recent area of their application includes matrix materials developed in the field of tissue engineering. Biodegradable polymers currently known and clinically used include poly(α-hydroxyacids), especially those of lactic and glycolic acids and their copolymers with ε-caprolactam (PCL). These polymers are polyesters which are made from lactide, glycolide and caprolactam monomers [6, 7]. The most known is poly(lactic acid) (PLA), due to its biodegradable and biocompatible features finding wide use in biomedicine. Depending on the application, this thermoplastic polymer can be processed into various structural forms of biomaterials, also with the use of textile technology [6, 8]. Characteristic properties of unmodified PLA include high crystallinity (about 40%), rigidity and a long time of degradation, which reduces its medical application [6]. Therefore in modifying its properties depending on the application, lactic acid is copolymerised with other biodegradable monomers, with glycolic acid being the most widely used. Biomaterials made of poly(glycolide-co-lactide) (PGLA) arouse a growing interest in medical areas. Products made of these copolymers find application in surgery for internal dressing in the process of soft organ therapy and in the form of plates, screws and shaped elements for implants in the regenerative treatment of bone defects. Clinical assessment tests of PGLA show a good biocompatibility of the material and a lack of negative local and systemic reactions. The biodegradable properties of the copolymer provide a complete resorption of the products by the human organism, thus eliminating the necessity of their surgical removal after therapy termination. They also determine tissue regeneration, improving the quality of patient therapy [8 - 10].

From the literature review [2, 3, 7, 11 – 13], it follows that in recent studies on dressing materials, the use of degradable synthetic polymers constitutes a new area of research. Medical biodressings have been made of polymers prepared with the use of chitin, a natural raw material with proven biocompatible action stimulating the process of wound healing [14 - 17]. Fibre and fabric structural modifications have been carried out already in the stage of fibre-forming polymer preparation, where, in addition to natural polymers, degradable synthetic polymers are also used for dressing materials [12]. The surface properties of materials are modified by coating and printing processes as well as by means of electrospinning, mainly with the use of biodegradable polymers [7, 17]. The technology of medical biodressing materials uses mainly nonwoven, nano-nonwoven and foam structures [7, 14 – 17]. The fibre-forming properties of degradable synthetic polymers used in medicine and the possibility of modifying fibre quality both at the stage of polymer preparation and in the spinning process now create new opportunities for the development of textile biomaterials.

One such opportunity is the technology of weft-knitted fabrics, constituting the object of the findings presented [2]. The experimental aim of the studies performed was to develop a structure of knitted fabrics designed for medical dressings, make structures designed by course knitting technology and assess the functional and medical properties of the materials obtained. It was intended to use yarns from continuous filaments made of degradable synthetic polymers and copolymers by a known method of melt spinning [5, 18, 19]. Multifilament yarns made of aliphatic polyesters and copolyesters show different structural and mechanical properties from those of yarns made of conventional polymers [20], which constitutes the basic problem of their use in knitting techniques [1 -3]. The relatively low tensile strength of aliphatic polyester fibres, their high elasticity and low yarn twist require one to produce the knitted fabrics under limited technological conditions.

*Table 1. Characteristics of qualitative parameters of degradable synthetic yarns; *yarn shrinkage was determined after immersion in water at a temperature of 95 °C, **yarn shrinkage was determined after immersion in water at a temperature of 60 °C.*

Polymer	Linear mass, dtex	Number of filaments, -	Tenacity, cN/tex	Elongation, %	Shrinkage, %
PLA 6201D	94.1	24	29.4	33.0	19.8*
	49.2	12	22.3	46.2	75.6*
	85.4	24	30.3	35.7	12.6*
	54.9	12	28.8	33.7	15.3*
	55.5	24	28.3	30.7	12.3*
PGLA	80.4	12	16.0	27.7	77.6**

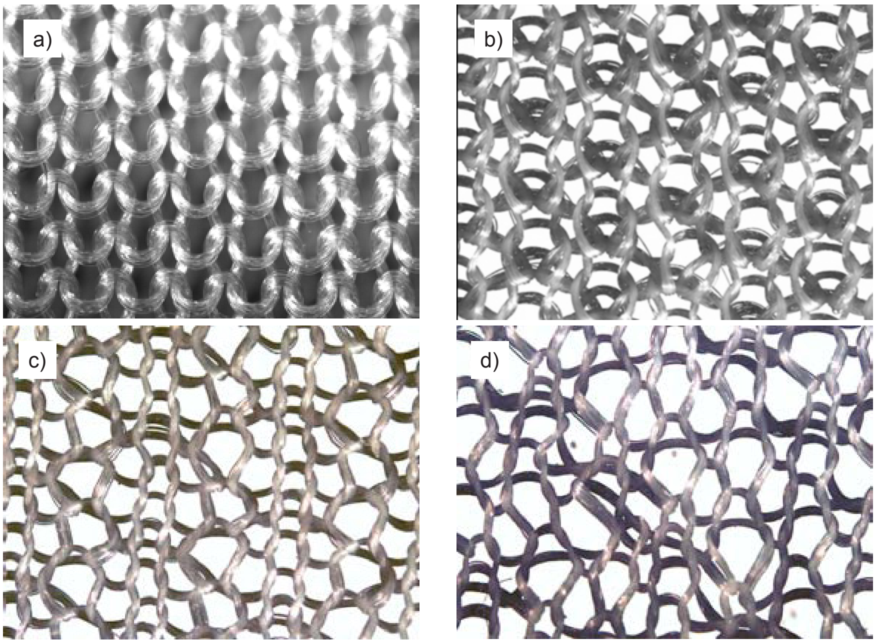

***Figure 1.** Real appearance of knitted fabrics made of degradable synthetic yarns with the stitch structures designed.*

Within the key-project "Biodegradable Fibrous Products – BIOGRATEX" [2], a technology of knitted fabrics of biodegradable polyester and copolyester yarns designed for dressing materials has been developed. Depending on the structural solutions developed, prototypes of the fabrics constitute medical dressings and sanitary dressing bandages.

Technological methodology and test methods

The technology of knitted fabrics was developed for multifilament yarns, made within the Biogrates project, from commercial polymer PLA6201D (NatureWorks LLC) and copolyester poly(glycolide-co-lactide) (PGLA) with 10% polymer a-PHB, which was made by Biogratex's partner - Centre of Polymer and Carbon Materials in Zabrze (Poland) - according to their own polymerisation methods [21, 22].The basic characteristics of qualitative parameters of yarns used in the experimental work are presented in ***Table 1*** [23]. As a result of the previous experimental work of the Research Textile Institute [1, 2] it was assumed that the linear density of continuous filament yarns of degradable polymers for course knitted fabrics should be from about 55 to about 87 dtex and the number of filaments 12 or 24. Using such assumptions, the yarns were produced by a partner of the Biogratex project – the Institute of Biopolymers and Chemical Fibre, Łódź (Poland) [25].

Fibre spinning was carried out with the use of Estesol PF 790 spinning preparation (Italy), admitted by FDA for medical applications. The thermal and fibre-forming properties of PLA 6201D and PGLA as well as fibre melt-spinning parameters are not discussed in this paper as they belong to the research tasks of the Institute of Biomaterials and Chemical Fibres – a partner of the Biogratex project [2].

Project assumptions of the knitted fabric structures were developed for course knitting technology. Considering economic aspects of the technology of potential dressing materials of new generation degradable copolyesters, project tasks were directed towards the use of plain stitches that provide a lower surface weight of knitted fabric compared to rib stitches, and consequently a lower consumption of yarn. The basic plain stitch selected for knitting is characterised by a uniform loop structure that provides, in turn, a uniform structure of dressing material and sensory comfort in contact between the user's skin and fabric face. The real appearance of the knitted fabric with the stitches selected is shown in ***Figure 1.a***. In the case of knitted fabrics designed for sanitary dressing bandages, it was decided to impart elasticity and increased porosity to the fabrics by using the structure of tucked plain stitches derived in the systems of tucked loops: 1 × 1, 1 × 2 and 1 × 3. The real appearance of these knitted structures is shown in ***Figure 1.b*** - ***1.d***.

To provide technological conditions of the knitting process depending on the linear mass of yarns, knitting machines with needle gauge 34 E were selected. Knitted fabric samples were produced with the use of an electronically controlled Edis 4.2 C knitting machine from Unipled (Czech Republic), equipped with a single system of 400 needles in a cylindrical needle bed with a diameter of 10.15 cm. Knitted fabrics with a structure of basic plain stitch were produced in a simple form of a tube that would make it possible to obtain a functional multi-layer structure of dressing material with an internal resorption layer. Knitted fabrics with plain tucked stitches were produced in a closed two-layer form constituting a functional shape of sanitary dressing bandages. During the knitting process, the border courses of the fabric were joined with an elastic yarn incorporated in the structure of these courses.

The structural and functional properties of the knitted fabrics were tested after their finishing process, consisting in treating the fabrics in a distilled water bath at a temperature of 40 °C for 5 min., followed by the wet relaxation of the fabrics for 48 h at ambient temperature, ca 25 °C.

To test the structural properties of the knitted fabrics, their thickness and surface porosity were determined. The surface porosity of the fabrics was measured

Table 2. *Test results of the basic structural and functional properties of the knitted fabrics (values given in the brackets stand for standard deviation; number of measurements is 5).*

Yarn	Kind of polymer	Polymer PLA 6201D					Copolymer PGLA
	Linear density, dtex	94.1 f24	49.2 f12	85.4 f12	54.9 f24	55.5 f12	80.4 F12
Stitch		Basic plain stitch			Plain derivative tucked stitch 1 × 1		
Thickness (*U*), *mm* (single fabric layer)		0.36 (0.02)	0.22 (0.02)	0.81 (0.03)	0.58 (0.03)	0.74 (0,02)	0.74 (0.04)
Thickness (*U*), *mm* (two fabric layers)		-	-	-	1.10 (0.02)	1.28 (0.03)	1.41 (0.06)
Surface porosity (*U*), %		51.2 (1.2)	47.1 (7.4)	63.7 (2.1)	81.4 (1.2)	68.3 (1.3)	70.1 (2.9)
Surface mass (*U*), g/m^2		72.0 (2.1)	27.1 (0.2)	71.8 (0.6)	46.2 (0.8)	47.3 (0.6)	70.4 (0.3)
Air permeability of fabric (*U*), *mm/s* (single fabric layer)		6022 (493) (100 Pa) 10236 (206) (200 Pa)	10800 (210) (100 Pa) > 15 000 (200 Pa)	7487 (92) (100 Pa) 11400 (137) (200 Pa)	9967 (139) (100 Pa) > 15 000 (200 Pa)	8038 (145) (100 Pa) 12320 (271) (200 Pa)	8242 (240) (100 Pa) 12400 (340) (200 Pa)
Air permeability of fabric (*U*), *mm/s* (two fabric layers)		-	-	-	6060 (134) (100 Pa) 9512 (203) (200 Pa)	5590 (75) (100 Pa) 8336 (187) (200 Pa)	5640 (180) (100 Pa) 8826 (700) (200 Pa)

using a measurement stand equipped with a biological microscope, Nikon Eclipse 50, with a lens with magnifying power ×2. According to the measurement procedure, the porosity index is the ratio of the sample clearance surface to the total sample surface. The tests of fabric functional properties included the determination of surface weight and hygienic parameters such as the air permeability, hygroscopicity, water absorption and drying time. Considering the two-layer functional form of the fabrics to be used as sanitary dressing bandages their thickness and air permeability were also determined in the product two-layer system. Both the knitted fabrics and final products were tested in the accredited Laboratory of Testing Textile Raw Materials and Fabrics (Textile Research Institute) in accordance to the standard requirements[1)] [24]. The sorption properties of the knitted fabrics were also determined by the Tegawa Drop Test according to the literature test procedure [25]. Sorption properties of the preliminary design of a medical dressing were assessed for the sample whose internal absorptive layer consisted of a commercial cotton compress in the form of Medicomp nonwoven with a surface weight of 40 g/m^2 and dimensions 5 × 5 cm.

The chemical purity of the fabrics designed for medical applications was assessed by determining their pH and the opacity of aqueous extract, chloride and sulfate ion contents and the presence of foam-forming agents and optical brighteners. These parameters were determined at the accredited Laboratory of Chemical Tests and Instrumental Analyses (Textile Research Institute) according to the test procedure[2)] [26]. In the assessment of the test results concerning the chemical purity of PGLA, we used the criteria for the materials designed for medical products according to the requirements of Tricomed S.A., a producer of medical goods [27]. In the current stage of the project realization [2], chemical purity was determined only for the knitted fabrics produced of PGLA.

Biodegradable properties of knitted fabric made of poly(glycolide-co-lactide) were determined investigating its hydrolytic degradation in a thermal chamber at temperatures of 37 and 70 °C. This sample of knitted fabric constitutes the results of earlier research work [1, 2]. Incubation was carried out in a phosphate buffer (pH 7.41) and in water, followed by the spectrometric analysis of degradation products by means of mass spectrometry ESI-MS. The tests were terminated after 180 days. The degradation process was monitored by determining changes in the sample weight of the polymer by the GPC method[3)]. These tests were performed by the partner of Biogratex project - the Centre of Polymer and Carbon Materials, Zabrze. The degradation tests of the knitted fabrics which are presented in this paper are during realization.

Results

During the production of knitted fabrics on the knitting machine selected, it appeared that the processing of synthetic yarns of degradable polymers was impeded due to the untwisted form of fibres in yarns. The basic criterion of selecting the parameters for making knitted fabric samples was fabric structure uniformity. The samples of knitted fabrics were made using a tension ranging from 1.7 to 2.5 cN and an optimal take-up depending on the linear density and knitting stitch. The technological solutions used to make knitted fabrics in the closed two-layer form allowed us to obtain sanitary bandages within the width range of 16.7 - 17.7 cm and with a height of 6.8 - 7.0 cm.

The organoleptic assessment of the knitted fabrics made with the use of the course stitches designed has shown that, in accordance with the assumptions, the knitted fabric developed for medical dressing shows beneficial features of the fabric face surface with respect to sensory comfort in contact with the user's skin. According to the assessment of the stitch structures designed for sanitary dressing bandages, cross resiliency was shown only by samples of the stitch variant made with the use of loop tucking in the 1 × 1 system (***Figure 1.b***). Moreover, the knitted fabrics made of degradable synthetic yarns showed a pleasant-to-touch, silky handle.

Test results of the structural and functional properties of the knitted fabrics constituting average measurement values with broadened uncertainty errors (*U*) are listed in ***Tables 2*** and ***3***. For the fabrics designed for sanitary dressing bandages, tests were performed for the stitch structure in a system of tucked loops 1 × 1. The sorption property test results of the preliminary medical dressing design of multi-layer structure, in which an absorptive nonwoven layer was inserted between the fabrics of degradable yarns, are presented in ***Table 4***. The chemical purity test results of the PGLA knitted

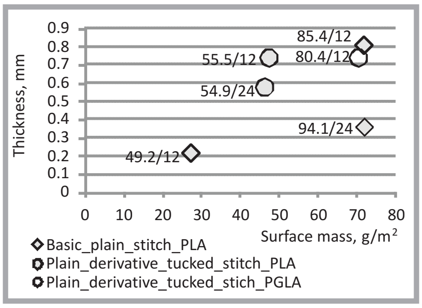

Figure 2. Dependence of the knitted fabric's thickness on surface mass.

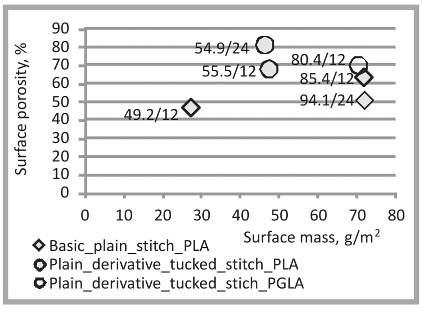

Figure 3. Dependence of the knitted fabric's surface porosity on surface mass.

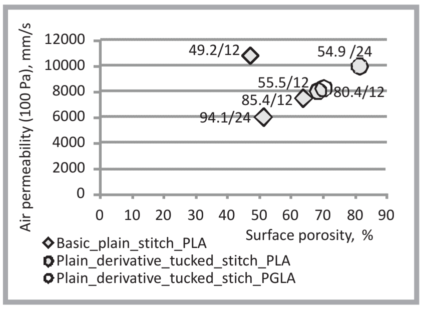

Figure 4. Dependence of the knitted fabric's air permeability on surface porosity.

fabrics are listed in ***Table 5*** and the hydrolytic degradation test results in ***Table 6***.

From the test results it follows that using the structure of plain derivative tucked stitch of yarns with a linear mass of 54.9 - 80.4 dtex we obtained fabrics with a surface weight ranging from 46.2 to 71.8 46.2 - 70.4 g/m^2. The surface porosity of the fabrics with a tucked stitch ranges from circa 60 to circa 80%, while the corresponding value of the fabrics with the basic plain stitch amount to circa 50%. The results of these tests and the values of air permeability show that the fabric samples analysed are characterised by various degrees of fabric structure filling. Nevertheless all the knitted fabric variants provide hygienic comfort within the parameter range investigated. To characterise the material investigated, average values of test results for one fabric layer (***Table 2***) are presented in ***Figures 2 – 4***. ***Figures 2*** and ***3*** show the fabric structural parameters depending on the fabric surface mass and ***Figure 4*** presents the air permeability of fabrics for measurements made under a negative pressure of 100 Pa depending on the fabric surface porosity.

*Table 3. Test results of fabric sorption properties (values given in the brackets stand for standard deviation, number of measurement is 5); * water drop percolates through the free spaces of the fabric structure.*

Yarn	Kind of polymer	Polymer PLA 6201D					Copolymer PGLA
	Linear density, dtex	94.1 f24	49.2 f12	85.4 f12	54.9 f24	55.5 f12	80.4 f24
Stitch		Basic plain stitch			Plain derivative tucked stitch 1 x 1		
Hygroscopicity (*U*), *%*		1.23 (0.36)	1.44 (0.60)	1.47 (0.15)	2.14 (0.21)	2.35 (0.31)	0.78 (0.09)
Water absorption (*U*), *%*		205 (42)	377 (39)	259 (58)	348 (39)	310 (31)	177 (23)
Drying time (*U*), *min*		47 (3)	40 (8)	35 (6)	48 (5)	42 (8)	30 (3)
Absorption time of a water drop (*U*),*s*		110 (9)	124 (16)	241 (14)	262 (15)	254 (7)	363 (19)
Dimensions of water drop absorbed, *mm x mm*		42 x 53	37 x 48	*note		4 x 5	*note

Table 4. Test results of the sorption properties of the preliminary multi-layer dressing design containing an internal absorptive layer (Values given in the brackets stand for standard deviation, number of measurement is 5).

Yarn	Kind of polymer	Polymer PLA 6201D	Copolymer PGLA
	Linear density, dtex	94.1 dtex f24	80.4 dtex f24
Stitch		Basic plain stitch	Plain derivative tucked stitch 1 x 1
Hygroscopicity, (*U*), *%*		12.6 (0.7)	9.5 (0.3)
Water absorption, (*U*), *%*		619.6 (72.3)	580.2 (48.1)
Time of water drop absorption, (*U*),*s*		106.4 (131.8)	2 (1)
Dimensions of absorbed water drop, *mm × mm*		11.2 × 6.8	11 × 7

Table 5. Chemical purity test results of the fabric made of PGLA yarn.

Parameter	Test results	Assessment criteria
pH of water extract -	5.8	5.5 ÷ 7.5
Opacity of water extract, mg SO_4^{-2}	below 1.2	below 1.2
Chloride ion content, mg Cl^- /g	below 0.0175	below 0.02
Sulfate ion content, mg SO_4^{-2}/g	below 0.04	below 0.05
Presence of foam-forming compounds	None	Nonpermissible
Presence of optical brighteners	None	Nonpermissible

The relationships shown in ***Figures 2*** and ***3*** for the knitted fabric sample with a basic plain stitch indicate that their variants made of PLA yarns with linear densities of 94.1 dtex f24 and 85.4 dtex f12 reached similar values of surface weight at higher values of thickness (by about 60%) and surface porosity (by about 20%) for the sample made of yarn with a linear density of 85.4 dtex f12. The fabric sample in this stitch group made of PLA yarn with a linear density of 49.2 dtex f12 shows a surface mass lower by about 75% compared to the remaining ones. This fabric variant shows thickness values lower by about 40% and 80% and porosity values - by about 10% and 35% compared to those of samples made of yarns with a linear density of 94.1 dtex f24 and 85.4 dtex f12, respectively. The knitted fabrics with plain derivative tucked stitches were made with the use of PLA yarn of similar linear density, about 55 dtex, and a filament number of 12 and 24, as well as PGLA yarns with a linear density of 80.4 dtex f12. The relationships shown in ***Figures 2*** and ***3*** illustrate that in this stitch group, the PLA knitted fabrics reveal similar values of surface mass and a 20% difference between the values of thickness and a 15% difference between those of surface porosity. The fabric variant made of PGLA yarn is characterised by similar values of thickness and surface porosity as the fabric variant of the same stitch structure made of PLA yarn with a linear density of 55.5 dtex f12. The value of surface mass for this fabric variant is, however, at the level of values obtained for fabric variants made with the use of basic plain stitch PLA yarns with a similar linear density to that of PGLA yarn.

Figure 4 illustrates the proportional dependence of air permeability on the surface porosity of the fabric presented, which is different for the fabric sample made with the use of basic plain PLA yarn with a linear density of 49.2 dtex f12. This fabric variant is characterised by a lower value of porosity at the lowest values of surface mass and thickness in relation to the remaining variants made with the use of a basic plain stitch. At the present stage of tests, the lower value of porosity for this fabric variant may be explained by the effect of untwisted filaments in the yarn structure, with different parameters of the knitting process forming yarns with different linear densities. In the group of fabrics with a plain derivative tucked stitch, it is observed that the fabric variant made of PGLA yarn with a linear density of 80.4 dtex f12 shows a similar value of air permeability to that of the variant made of PLA yarn with a linear density of 55.5 dtex f12 at similar values of surface porosity and thickness.

Data from ***Table 2*** concerning values of average thickness and air permeability depending on the surface mass for fabrics with plain derivative tucked stitches in a two-layer system and for one fabric layer are shown in ***Figures 5*** and ***6***. These illustrate the basic parameters of fabrics designed for hygienic dressing bands that assume their form in a closed two-layer fabric system. Using the structure of plain derivative tucked stitch in the system of tuck loops 1 × 1 for two fabric layers of PLA yarn with a linear density of about 50 dtex f24 and f12 proposed for making the dressing bands, appropriate fabrics with thicknesses of 1.10 and 1.28 mm and a surface mass of about 90 g/m^2, while using PGLA yarn with a linear density of 80.4 dtex f12, the fabric obtained had a thickness of 1.41 mm and surface mass of about 140 140 g/m^2. Knitted fabrics in a two-layer system of yarn types used show similar values of air permeability, but in the case of a single fabric layer, these values are lower by about 30 % with the use of yarn containing 12 filaments and by about 40% with the use of yarn containing 24 filaments.

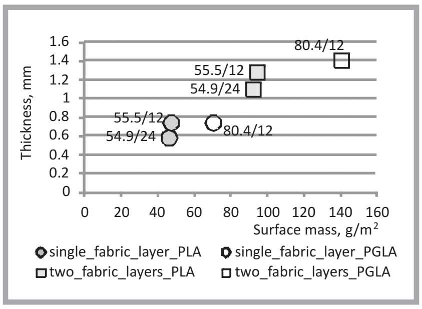

Figure 5. *Dependence of the knitted fabric's thickness on surface mass.*

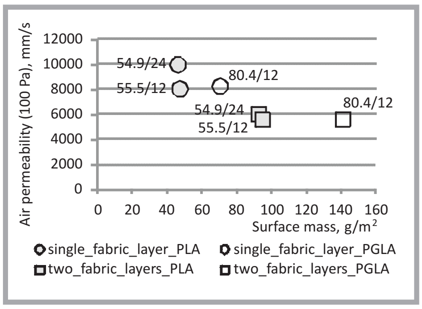

Figure 6. *Dependence of the knitted fabric's surface porosity on surface mass.*

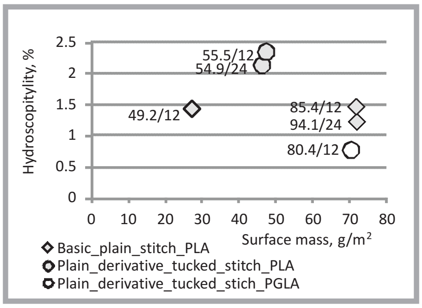

Figure 7. *Dependence of the knitted fabric's hygroscopcity on surface mass.*

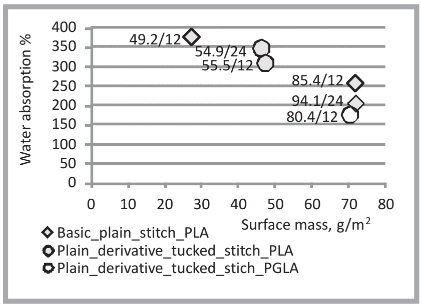

Figure 8. *Dependence of the knitted fabric's water absorption on surface mass.*

From the test results of sorption properties listed in ***Tables 3***, it follows that the fabric made of PGLA is characterised by considerably lower values of these parameters compared to those of PLA fabrics, with a longer time of drop absorption determined by the Tegewa Drop test. The sorption property test results of the fabrics indicate hydrophobic properties being characteristic of these synthetic polymers [28]. The hygroscopicity, water absorption and absorption time values obtained are similar to those of knitted fabrics made of conventional continuous polyester filaments. The Tegewa Drop test results of the dimensions of the water drop absorbed show the influence of the type of fabric stitch structures and porosity on the value of this parameter. Characteristics of the average values of hygroscopicity and water absorption listed in ***Table 3*** are illustrated in ***Figures 7*** and ***8*** as a function of the fabric surface mass. ***Figure 9*** illustrates the dependence

Table 6. *Hydrolytic degradation test results of the fabric made of poly(glycolide-co-lactide) [1].*

Degradation temperature	Degradation time, 24 h	Change in water pH during degradation	Sample weight before degradation	Sample weight after degradation	Weight change, %
Biomixed 37	0	6.32	-	-	-
	3	7.23	0.0145	0.0166	+14.5
	7	6.80	0.0127	0.0138	+8.7
	10	6.80	0.0109	0.0120	+10.1
	20	6.79	0.0100	0.0103	+3.0
	30	6.67	0.0169	0.0175	+3.5
	60	6.11	0.0124	-	-28.4
	90	4.97	-	-	-39.2
	180	4.08	-	-	-85.2
Biomixed 70	0	6.32	-	-	-
	3	4.30	0.0123	0.0112	-8.9
	7	3.67	0.0195	0.0159	-18.5
	10	3.48	0.0145	0.0038	-73.8
	20	3.20	0.0150	0.0021	-86.0
	30	3.26	0.0152	0.0022	-86.0
	60	3.16	0.0141	-	-100.0
	90	3.12	0.0186	-	-100.0
	180	3.10	0.0149	-	-100.0

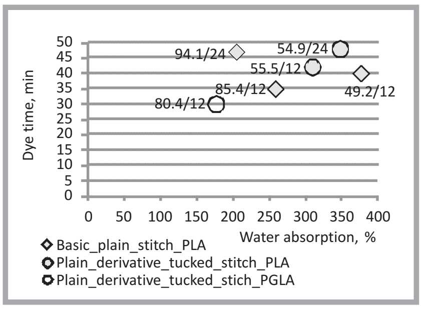

Figure 9. *Dependence of the knitted fabric's drying time on water absorption.*

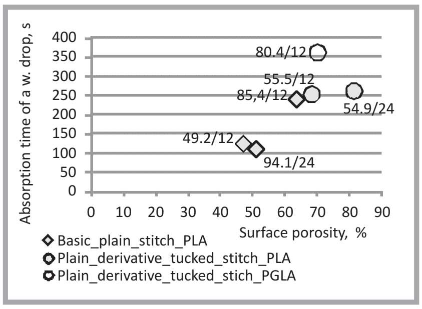

Figure 10. *Dependence of the knitted fabric's drying time on surface porosity.*

of the fabric drying time on water absorption, while ***Figure 10*** shows the effect of the fabric surface porosity on the water drop drying time.

With reference to the knitted fabrics presented in this study, it is observed that in the case of using PLA yarns, the stitch structure is a significant factor affecting the fabric's hygroscopic properties. The dependence shown in ***Figure 7*** indicates that the highest values of hygroscopicity were obtained for fabric samples made of PLA yarns with a plain derivative tucked stitch. Analysing the hygroscopicity parameter, one cannot observe any significant effect of the linear density of the PLA yarns used and fabric surface mass. The parameters shown in ***Figure 8*** illustrate the inversely proportional dependence of water absorption on the surface mass of the fabric presented, which indicates that the materials have hydrophobic properties. Based on the tests performed, one can observe an increase in the value of fabric water absorption with the decreasing linear density of PLA yarns, while in the case of fabric variants made with the use of a plain derivative tucked stitch, this parameter increases with a rise in the number of filaments in the PLA yarn. The results of testing the absorption properties of the knitted fabrics (***Table 3***) show that the highest value of the drying time was obtained for fabric variants made of PLA yarns containing 24 filaments. From the values presented in ***Figure 9*** it follows that the drying time of the materials presented depends on the linear density of yarn and the number of filaments as well as on the fabric structure. The lowest value of drying time with the highest water absorption was obtained for the fabric variant made with the use of PLA yarn with a basic plain stitch and linear density of 49.2 dtex f 12. The results of testing the fabric absorption properties with the use of the Tegewa Drop Test [25] (***Table 3***) show, in the case of three fabric variants, a complete penetration of the fabric sample by water without any symptoms of its absorption on the fabric surface. The results of testing the parameters under analysis allow us to indicate beneficial structural solutions in relation only to two knitted fabrics made of PLA yarns with a basic plain stitch and linear densities of 94.1dtex f24 and 49.2 dtex f12. The test results of these fabric variants show their capability to absorb a drop of water on the fabric surface with similar values of the water drop absorption time and size of water drop absorbed, but with a circa 50% difference between the values of water absorption. The results of testing the absorption properties of the materials under investigation show that these features depend, first of all, on the type of yarns, number of filaments in yarns and the fabric structure. The test results given in ***Figure 10*** illustrate the

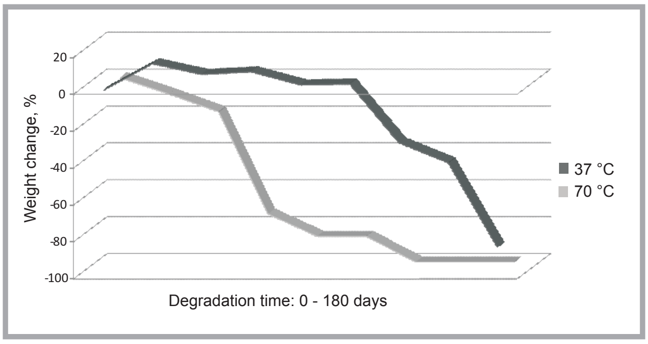

Figure 11. *Relative change in the PGLA fabric mass due to its hydrolytic degradation.*

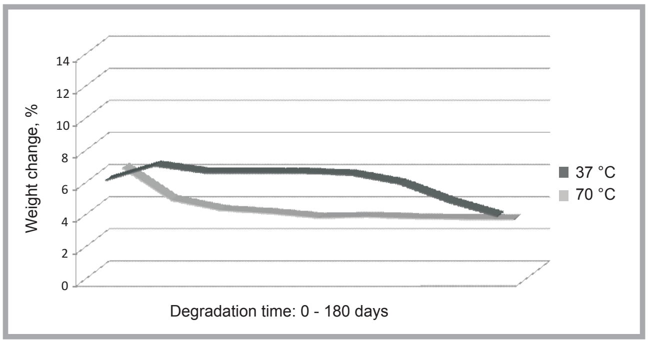

Figure 12. *Change in pH of water due to the hydrolytic degradation of PGLA fabric.*

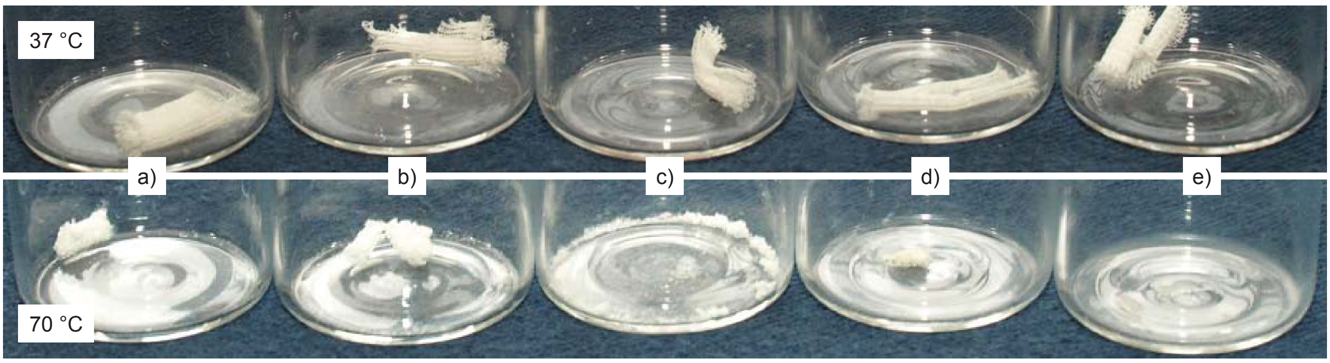

Figure 13. *Macroscopic changes in the knitted fabric made of poly(glycolide-co-lactide) yarn subjected to hydrolytic degradation after: a) 3, b) 7, c) 10, d) 20 and e) 30 days.*

dependence of the water drop absorption time on the fabric surface porosity. The values presented show a proportional dependence of the parameters analysed for the fabric variants made of PLA yarns, while in the case of samples with higher porosity values, the test results show water drop penetration through the fabric structure.

The incorporation of an absorptive layer in the form of cotton nonwoven into the fabric imparts to it the features of medical dressing such as hygroscopicity and water absorption [28]. The analysis of the surface sorption properties of the multi-layer fabric indicates a beneficial effect of increased fabric porosity (***Table 2***) on water transport, as determined by the Tegewa Drop test.

Analyses of aqueous solutions carried out by the ESI – MS method after specified periods of hydrolytic degradation showed that the water-soluble degradation products of the fabric made of poly(glycolide-co-lactide) are lactic and glycolic acids and their oligomers. After longer degradation periods the water-soluble products contained more lactic acid and its low-molecular oligomers. The results of these tests indicate that the process of fabric hydrolytic degradation occurs under the conditions tested, with the degradation period being dependent on the temperature used. The sample tested at a temperature of 70°C had been totaly decomposed after 60 days of incubation. The test results listed in ***Table 6*** are illustrated in ***Figures 11*** and ***12***.

The real appearance of macroscopic changes in the knitted fabric sample hydrolytically degraded at a temperature of 37 and 70 °C are shown in ***Figures 13.a*** and ***13.b***.

Conclusions

The test results presented in this paper constitute a recognition area of actions within the scope of knitted fabrics made of degradable synthetic polymers for medical dressing materials. The continuous filament yarns assessed with respect to technological parameters were produced on a large-laboratory scale according to parameters optimised by the project partner – Institute of Biomaterials and Chemical Fibres, Łódź. The level of the yarn quality parameters obtained (***Table 1***) makes it possible to produce knitted fabrics by the course knitting technique; however, some limitation is imposed by the untwisted form of filaments in the yarn. The attempt undertaken in this study to analyse metrological results for the fabric samples presented indicates the necessity of extending studies on the assessment of the effect of polymer type as well as yarn and fabric structures on the functional properties of materials designed for specified medical applications. The assessment results of the fabric stitch structure proposed confirmed the soundness of the solutions accepted for medical dressing and sanitary dressing bandages. In view of the hydrophobic properties of PLA and PGLA filament yarns, it has been found possible to provide appropriate features of dressing material by using a multi-layer fabric structure containing an absorptive internal layer, with the knitted fabric being characterised by a low parameter of its structure filled with yarn. The assessment of the fabric sorption properties by the water absorption test showed the beneficial effect of the uniform fabric structure, which predestines the use of a plain course stitch for fabrics designed for medical dressing materials. It should also be emphasised that fabrics made with this kind of course stitch, using the yarns selected in this study, can impart sensory comfort to dressings through their silky handle and smooth surface structure. The technological solution assumed in the study for knitted fabrics to be used as dressing bandages makes it possible to produce goods with dimensions adapted to both limbs. The assessment of the plain derivative tucked stitch structure proposed allowed us to select a solution that imparts lateral resilience to the dressing. The metrological assessment of the fabrics showed that they have hygienic properties determined by the air permeability parameter, which will provide user comfort.

The hydrolytic degradation tests confirm that knitted fabric made of poly-(glycolide-co-lactide) yarn shows degradable properties. From the tests results it follows that the degradation process proceeds faster at a temperature of 70 °C than at 37 °C, as confirmed by the change in the fabric sample weight and the lowered pH in the case of incubation in aqueous solutions.

The assessment of the fabric chemical purity, which in the current stage of studies has been carried out on knitted fabric made of PGLA yarns, allows one to use it for medical applications. The assessment of knitted fabrics made of degradable polymers for medical dressings presented in this paper now constitutes a subject of research at the Textile Research Institute, including an analysis of cytotoxicity as well as an evaluation of hemolytic, irritative and alergenic properties and in vitro tests. In vitro tests are conducted according to Standard PN – EN ISO 10993 – 1 : 2010. Tests within this scope are carried out by the Biogratex project partner - the Medical University of Wroclaw. The medical materials of this group are sterilised with a radiation dose of 28 kGy.

Editorial notes

1) *The accredited Laboratory of Testing Textile Raw Materials and Fabrics (Textile Research Institute)*
2) *The accredited Laboratory of Chemical Tests and Instrumental Analyses (Textile Research Institute)*
3) *Centre of Polymer and Carbon Materials, Zabrze.*

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