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Possibility of using polyamide 6 reinforced with glass fiber for Ilizarov rings

Summary — In this work, estimation of possibilities of using polyamide 6 (PA6) reinforced with glass fiber for Ilizarov rings applied in medicine as fixation systems was presented. Two types of composites on the base of PA6 with 25 and 50 wt. % of glass fiber (PA6/25GF and PA6/50GF, respectively) were used. Mechanical properties were tested on injection molded dumbbell specimens to determine material properties for numerical modeling. The numerical analysis of stresses and deflection for different thickness of ring was done to optimize its shape. After that analysis, two types of rings were injected from PA6/50GF and for comparison similar composite with carbon fiber was used. Composite rings were tested under bending load to estimate the correctness of processing and agreement with numerical calculation.
Key words: polyamide 6 composites, Ilizarov rings, mechanical properties, numerical modeling.

OCENA MOŻLIWOŚCI ZASTOSOWANIA POLIAMIDU 6 WZMOCNIONEGO WŁÓKNEM SZKLANYM DO WYTWARZANIA PIERŚCIENI ILIZAROVA

Streszczenie — W pracy przedstawiono ocenę możliwości zastosowania poliamidu 6 (PA6) wzmocnionego włóknem szklanym na pierścienie Ilizarova stosowane w medycynie jako elementy fiksatorów (rys. 1). Zastosowano dwa rodzaje kompozytów na osnowie PA6 o zawartości włókna szklanego 25 i 50 % mas. (odpowiednio PA6/25GF i PA/50GF). Na wytworzonych metodą wtryskiwania kształtkach w postaci wiosełek wykonano badania właściwości mechanicznych w celu wyznaczenia wielkości materiałowych do obliczeń numerycznych. W celu optymalizacji kształtu pierścienia dokonano numerycznej analizy rozkładu naprężeń i ugięć przy założeniu różnych grubości tych pierścieni. Po analizie wytworzono metodą wtryskiwania dwa rodzaje pierścieni z kompozytu PA6/50GF i dla porównania z podobnego kompozytu zawierającego włókna węglowe (rys. 2). Aby ocenić poprawność wykonania pierścieni poddano je badaniom mechanicznym z zastosowaniem obciążeń zginających. Wyniki badań właściwości mechanicznych pierścieni potwierdziły poprawność i przydatność modelowania numerycznego pierścieni Ilizarova (rys. 3, 4).
Słowa kluczowe: kompozyty poliamidu 6, pierścienie Ilizarova, właściwości mechaniczne, modelowanie numeryczne.

An external fixation system is an apparatus, in medicine, used to cure fractured or deformed bones of legs, hands and pelvis. Its role is to keep the bone in place and stabilize it with pins and wires. Wires are pieces that pass through the bone and are connected to a rigid frame. The adjective "external" is employed when talking about fixation systems of which frame is linked but out of the limb. Thus we can differentiate them with internal fixation system. There are many different shapes of external systems and they can fix a variety of broken bones [1, 2].

The first external fixation system was developed in 1951 by a Russian: Dr Gavriil A. Ilizarov. Not really known until recent times, this technique is more and more used today to correct bone deformities and fractures. Quality (modularity and dynamization) of the apparatus was unknown even at the beginning of the eighties in Europe. But since 1950s, 1 million cases worldwide have proven that the Ilizarov system works. Today the classical system is much more used for bones of legs (like tibias), fingers and animal members [3, 4]. In other cases (femur, humerus) Ilizarov fixators have changed for external hybrid fixators (mono-lateral) due to dimensional, hygiene and quality of life reasons. The Ilizarov concept combines advantages of orthopaedic treatment and surgical treatment, without drawbacks of the last one, as immobilization [3]. Thus, patients can walk, ride a bike, and do some other activities [5]. This system is made of around 20 simple mechanical devices (rings, rods, wires, bolts and hinges) and can be assembled in more than 600 different ways. Generally, the frame consists of circular rings with interconnecting rods and each device has a specific place and function. Used for children or small animal limbs, this ring has an

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external diameter going from 80 to 150 mm according to the need of the patient [2, 4]. It has the same geometry as a big ring but does not support the same patient's weight, so it does not need to have the same mechanical properties. For those reasons, we can also find small rings made of aluminium. We decided to choose a material of research according to its good radio-transparency (low crystallinity), its weight (low density) and its price. Reinforced polyamide 6 with glass fiber meats to these criteria [4, 6].

EXPERIMENTAL

Materials

Polyamide 6 (PA6) was provided by Zakłady Azotowe S.A. in Tarnów-Mościce. Polyamide 6 has high molecular weight, relative viscosity was 2.9—3.8, content of monomer was below 0.3 wt. % and content of moisture below 0.05 wt. %. PA6 was modified by glass fiber of diameter about 10 μm (another properties of fiber are manufacturer's trade secret).

Sample preparation

Specimens for mechanical tests were prepared by injection molding (temperature 260—290 ^{o}C, mold temperature 80—100 ^{o}C, velocity 90 mm/s, pressure 90 MPa) from polyamide 6 with glass fiber (25 or 50 wt. % of glass fiber).

Besides dry samples the humid ones were prepared. Humid samples were obtained by immersing in water for 24 hours.

Ilizarov rings were prepared by injection molding of PA6 with 50 wt. % of glass fiber and for comparison also of polyamide 6 with 50 wt. % of carbon fiber.

Methods of testing

Absorption of water by tested composites was measured according to PN-EN ISO 62:2000.

Tensile tests were carried out for the composites at 21 ^{o}C and 65 % relative humidity (*RH*) using automatic tensile tester (Instron type 4465) according to PN-EN ISO 527.

Bending tests for Ilizarov rings were done (according to scheme shown in Fig. 3) at 21 ^{o}C and 65 % of *RH* using Instron automatic tensile tester [7].

RESULTS AND DISCUSSION

Choice of material for Ilizarov rings

Mechanical properties of dry and humid PA6 composites were tested. Properties of samples according to the percentage of glass fiber and the content of water are compared in Table 1.

For both dry or humid samples, the results of tests show that the more of glass fiber in PA6, the higher tensile strength [8]. Addition of glass fiber improves the Young's modulus, but also decreases the deformation [9]. This fact could be a problem for applications which need to use deformable materials. But in our case, we are looking for a material which mechanical behavior gets closer to the one of metals. It is why reinforced PA6 with 50 wt. % of glass fiber should be the best material, in comparison with pure PA6 and PA6/25GF.

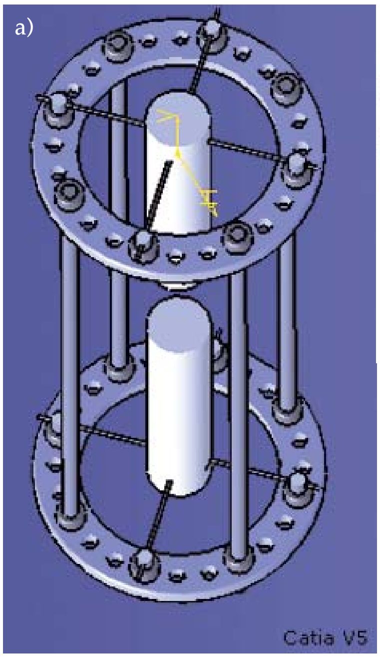
T a b l e 1. Mechanical properties of dry and humid PA6 composites reinforced with glass fibers

Symbol of sample	Glass fiber content wt. %	Dry samples			Humid samples		
		water content wt. %	tensile strength MPa	Young's modulus, MPa	water content wt. %	tensile strength MPa	Young's modulus, MPa
PA6/0GF	0	0.2	74	3100	1.5	55	2450
PA6/25GF	25	0.2	164	8200	0.9	130	6570
PA6/50GF	50	0.2	232	17 000	0.4	198	16 400

Simple final elements — modeling and results

A model of Ilizarov apparatus in simple conditions of positioning for small limbs presented in Fig. 1 was done with Catia V5 programme [10]. It is composed of two parallel rings, four rods, four wires, eight elements which tie the wires to rings, and thirty two nuts that hold in position the elements among them. We modeled a ring directly by Ansys programme. All rings (with different thicknesses) were divided in four volumes in the thickness. This operation let impose a maximum thickness to next formed elements [11]. Then we did a free meshing with 3D solid elements composed by 20 nodes. We could observe that the meshing is more refined near holes. All models of ring have the same loading distribution, using four main holes numbered from 1 to 4, positioned on perpendicular axes.

We decided to apply a loading of 500 N (approximate maximus load applied on small rings) divided in to 20 loads of 25 N each. 10 loads are distributed on 10 nodes around a circle of a hole, in the opposite direction of



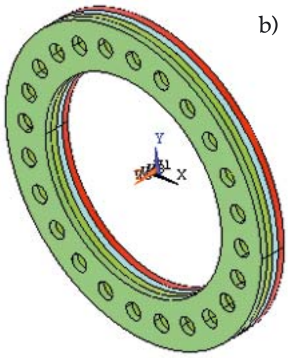


Fig. 1. Model of Ilizarov apparatus (a) and numerical model of a ring with meshed elements dependent on thickness (b)

Fig. 2. Ilizarov apparatus made of PA6/50GF

axis z. It means holes 3 and 4 support, each one, a load of 250 N. Results of calculation for different materials of the same thickness of 5 mm are shown in Table 2.

T a b l e 2. Comparison of the rings made of different materials with the same thickness of 5 mm

	Aluminium	PA6/0GF	PA6/25GF	PA6/50GF
Maximum total displacement, mm	0.48	13.61	5.08	2.03
Maximum equivalent von Mises stress, MPa	307	306	306	306
Maximum von Mises total strain, %	0.007	0.203	0.076	0.031

Ta b l e 3. Comparison of the rings made of PA6/50GF with different thickness

Thickness of a ring, mm	7	8	9
Maximum total displacement, mm	0.78	0.54	0.38
Maximum equivalent von Mises stress, MPa	248	228	124
Maximum von Mises total strain, %	0.025	0.023	0.012

We can deduce that, in comparison with aluminium, a ring of PA6/50GF 5 mm thick does not present good results. In fact, maximum displacement (2.03 mm) is too high. We will try to optimise the thickness of reinforced polyamide ring to obtain good properties without preparation of very thick ring. Results which were calculated for PA6/50GF with thickness of 7, 8 or 9 mm are shown in Table 3. Moreover, we can observe that maximum equivalent von Mises stress decreases when the thickness increases. It is logical because of the geometry of the ring. But the value for 9 mm thickness is too low in comparison with the others. We can explain this taking

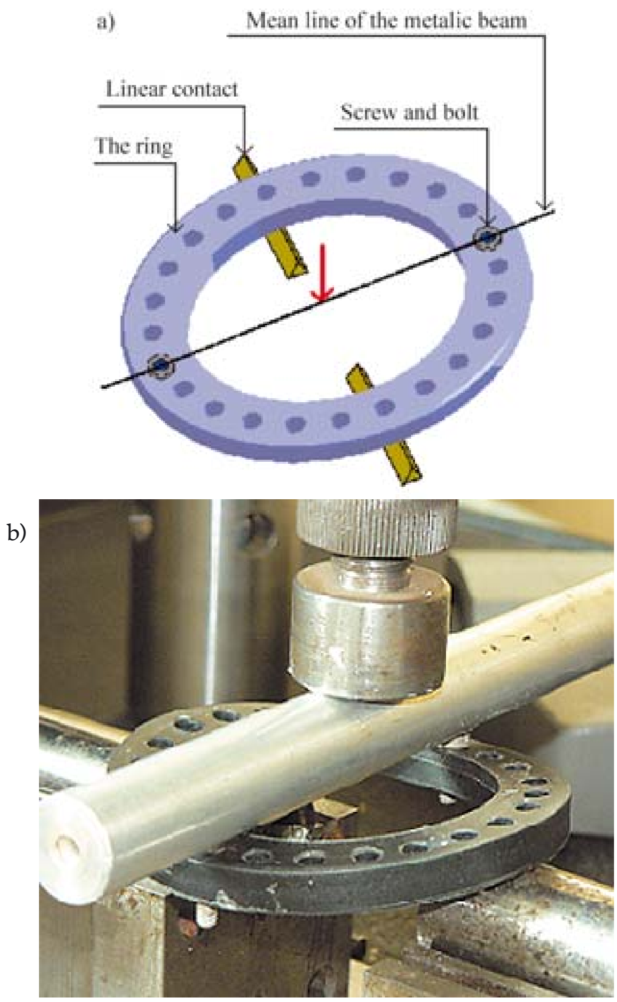


Fig. 3. Configuration of the bending tests (a) and moment of testing (b)

into account the sizes of elements. In fact, the ring with a thickness of 9 mm has 23 187 elements, that induces a bigger size of elements and it can not be compared with others rings. Those results show that a composite ring with a thickness of 8 mm is the one, which is closest to the results required.

Tests of injection molded rings

We pierced the injected rings with different numbers of holes, some with 16 holes, the others with 24 holes (pierced each 15^{o} as in the previous modeling). For both numbers, the diameter of each hole was 5 mm. All rings were pierced in our laboratory of Mechanical Department of Cracow University of Technology. Figure 2 presents Ilizarov apparatus made of PA6/50GF.

We performed the tests of the rings made of PA6/50GF and the rings made of PA6 reinforced with 50 wt. % of carbon fiber. Moreover, for each material, we made tests for the rings with 16 holes (22.5^{o} between each two holes) and the rings with 24 holes (15^{o} between each two holes). Comparing the results of the previous modeling, presented in table 3 and 4, and this test, we can observe that the configurations of deformation of rings made of PA6/50GF under 500 N are the same (Figure 3).

Bending tests were made for the rings made of PA6 reinforced with 50 wt. % of glass or carbon fibers.

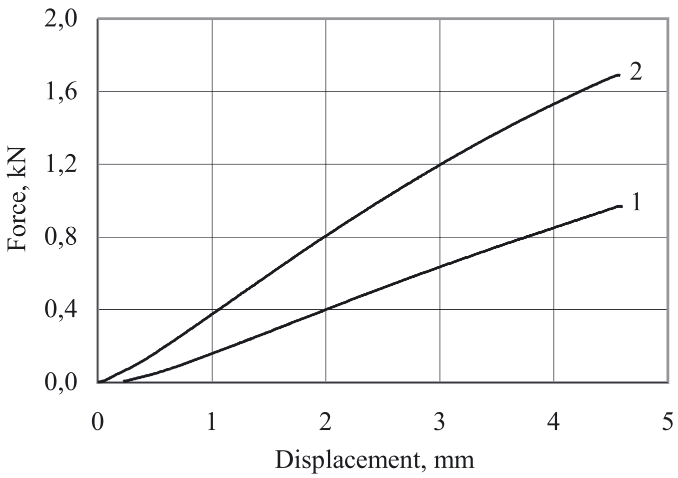


Fig. 4. Comparison of bending tests results for the rings made of PA6 with 50 wt. % of: 1— glass fiber, 2 — carbon fiber

Comparison of the results of this test for both rings, presented in Figure 4, confirms that carbon fibers let obtain better properties than glass fibers. We observe that the ring with carbon fiber can withstand a higher load for the same deformation. It is why these fibers are already used to make Ilizarov rings and are taking the place of steel in the case of big rings (used for adults or big pets).

CONCLUSIONS

All modeling and tests show that, under some conditions, the rings made of PA6/50GF could be used to produce Ilizarov apparatus. They also enable to optimize thickness of the ring. The first modeling showed that a small ring made of PA6/50GF with a thickness of 8 mm was the model which gave the best results in comparison with popular aluminum ring. All those models and tests just considered the load created by the weight of the patient, disregarding the others. Ilizarov rings made of PA6 composites with high content of fiber can be applied in pediatrics and veterinary to connect small bones in place of metal rings used until now. Additionally they make easier Roentgen images analyses [2].

Having know that this ring can handle the maximum value of this load, and also that the properties of the material are better along the direction of fibres, it would be interesting to make a model and the tests according to the other applied loads to find in which direction the fibres would have to be injected to obtain the best properties to withstand the whole loading.

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