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Estimation of mechanical (static and dynamic) properties of recycled polypropylene filled with wood flour*)

Summary — PP recyclate was filled with two commercial types of wood flour. The effects of the filler content (10 or 20 wt. %) and the dimensions of its particles (70—150 μm or 300—500 μm) on the useful characteristics of the composites obtained were studied. The following features were evaluated: static and dynamic mechanical properties including the ability to energy dissipation as well as creep course. It was found that the filling of recyclate with wood flour influence advantageously the properties investigated and the better results were obtained for the filler of smaller dimensions of particles. Scanning electron microscopy method let find that the presence of the filler investigated, showing good adhesion to polypropylene matrix, caused decrease in PP spherulites dimensions.
Key words: polypropylene, recyclate, wood flour, composite, useful properties.

OCENA MECHANICZNYCH (STATYCZNYCH I DYNAMICZNYCH) WŁAŚCIWOŚCI RECYKLATU POLIPROPYLENU NAPEŁNIONEGO MĄCZKĄ DRZEWNĄ
Streszczenie — Recyklat PP napełniano dwoma handlowymi typami mączki drzewnej i zbadano wpływ zawartości napełniacza (10 % mas. lub 20 % mas.) oraz wymiarów jego cząstek (70—150 μm bądź 300—500 μm) na użytkową charakterystykę uzyskanych kompozytów. Oceniano przy tym następujące cechy: statyczne właściwości mechaniczne (rys. 1—3), dynamiczne właściwości mechaniczne łącznie ze zdolnością do rozpraszania energii (rys. 5—8), a także przebieg pełzania (rys. 4). Stwierdzono, że napełnianie recyklatu PP mączką drzewną korzystnie wpływa na badane właściwości, przy czym stosowanie mączki z cząstkami o mniejszych wymiarach prowadzi do lepszych wyników. Metodą skaningowej mikroskopii elektronowej ustalono, iż obecność badanego napełniacza, wykazującego dobrą adhezję do matrycy polipropylenowej, powoduje zmniejszenie wymiarów sferolitów PP (rys. 9 i 10).
Słowa kluczowe: polipropylen, recyklat, mączka drzewna, kompozyt, właściwości użytkowe.

Wide use of polymeric materials creates problem of growing quantity of waste and possibility of using recycled materials is limited because of inferior properties of recycled plastics to virgin ones. One of the possibility to improve the properties of plastic products is using diverse fillers like *e.g.* glass or carbon fibres. Among the functional fillers, natural fibres have become a common material for the manufacture of filled plastics as well. Natural fibres reinforced composites seem to be a good alternative to glass fibres in some technical applications because of number of advantages they provide, such as renewable character, an easy combustibility and low cost [1—5]. The wood/plastics composites cover a wide range of polymer matrix types (including PP, PE and PVC) as well as wide range of fillers including wood fibres, flax, hemp, jute and other cellulose based fibre fillers. Polyethylene is most commonly used in exterior applications, and polypropylene for automotive and consumer applications. The majority of current applications are in USA and Japan but use of natural and wood fibres in composites applications is starting to interest people also in Europe [6—7].

The mechanical properties of the composites are strongly affected by the quantity of the wood filler in material. In this paper composites of up to 20 % part of wood fibre (wood flour) were tested. With such a part of wood they can be extruded in classic extrusion lines. Composites based on natural fibres show light weight, high strength to weight ratio and good stiffness. However, there can be the problems with the technical properties of reinforced materials — moisture absorption is generally high and impact strength is relatively low [8—14].

In order to evaluate the possibility of using the recycled polymers instead of virgin ones and wood fibre

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composites' usefulness, recycled PP composites with two types of wood fibres were tested regarding their mechanical and dynamic properties. Wood fibres added to PP were different in terms of the shape and the size of particles.

EXPERIMENTAL

Materials

Wood/plastics composites were based on recycled polypropylene (PP) recovered from car bumpers (produced by ZPTS Klaj, an injection molding type, *MFR* = 3.3 g/10 min). As the fillers there were used two kinds of wood flour — Lignocel CB 120 and Lignocel BK 40/90 — produced (by J. Rettenmaier & Sohne GmbH + Co) from soft wood. Characterizing parameters of wood flour are shown in Table 1.

T a b l e 1. Charecteristics of lignocel flours

LIGNOCEL	Raw material	Structure	Particle size, μm	Bulk density g/l	Humidity, %
CB 120	soft wood	fibrous	70—150	100—145	≤6 %
BK 40/90	soft wood	cubic	300—500	170—230	≤15 %

Specimens were prepared by injection molding (temperature 210 °C, form temperature 35 °C, velocity 90 mm/s, pressure 105 MPa) from recycled polypropylene composites with two types of wood fibers (10 and 20 % of wood fiber weight content).

Methods

— Tensile tests were carried out for the composites at 21 °C and 65 % RH using an automatic tensile tester (Instron type 4465) according to PN-EN ISO 527.

— Properties under dynamic loading were tested using dynamic machine in tensile test (Instron type 8511.20) on the level of frequency 5 Hz for 5000 cycles. Cyclic loading was within the range 0.1—0.5 of average maximum force reached in tensile test. Computer program was created to convert numerical data from tensile machine and to calculate mechanical properties including modulus of elasticity, elongation, creep effects and dissipation of mechanical energy during sequence of hysteresis loops.

— The creep test was performed using the machine by own construction parallel for 5 specimens (10 × 4 mm) by stress on the different levels, average for 20 days. Loading system ratio was 5 to 1. Accuracy of apply a load was 0.5 N and increase in elongation was measured by mechanical extensometers with accuracy 0.01 mm.

— The tensile fracture surfaces and fractured surfaces generated by breaking of the specimen under liquid nitrogen conditions were studied, using scanning electron microscope (SEM) Joel JSM 5510LV (low vacuum).

RESULTS AND DISCUSSION

The results of tensile test of PP composites are represented in Fig. 1, 2 and 3. By increasing content of wood

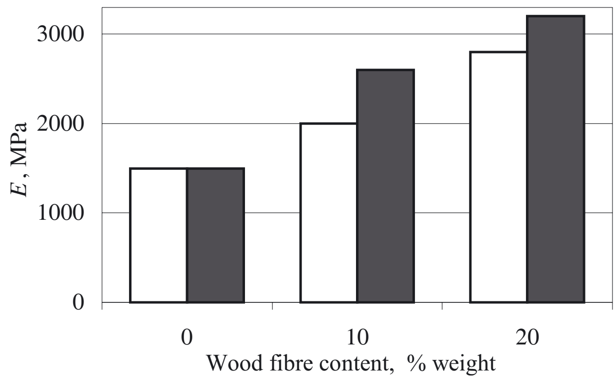

Fig. 1. Comparison of tensile modulus (E) of the composites of recycled PP with different content and type of wood flour; □ *— CB 120,* ■ *— BK 40/90*

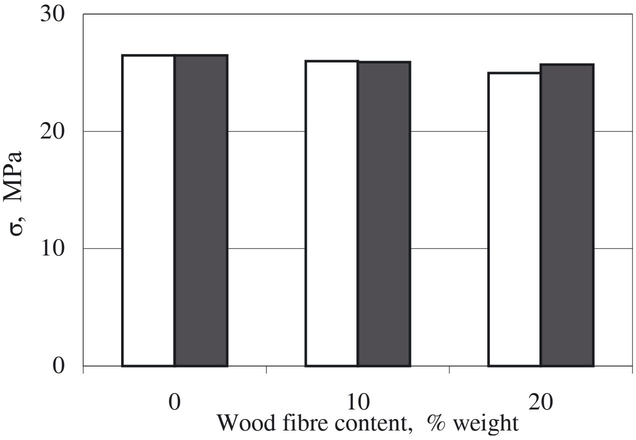

Fig. 2. Comparison of tensile strength (σ_M) of the composites of recycled PP with different content and type of wood flour; □ *— CB 120,* ■ *— BK 40/90*

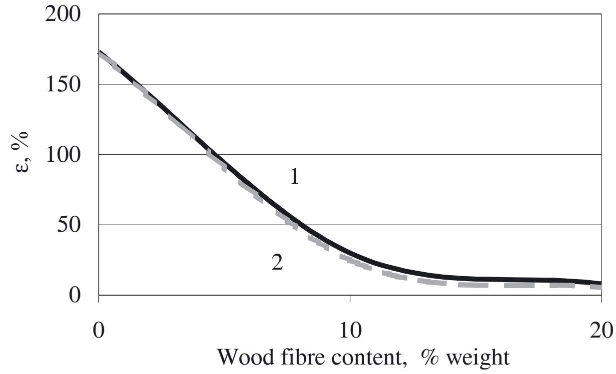

Fig. 3. Comparison of elongation at break (ε) of the composites of recycled PP with different content and type of wood flour, 1 — PP with CB 120, 2 — PP with BK 40/90

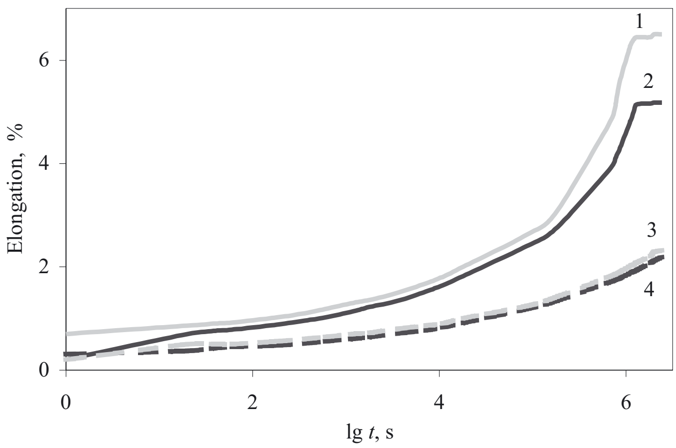

Fig. 4. Creep curves, illustrating the dependence of elongation on time (t), for recycled PP filled with wood flour: 1 — PP + 10 % of CB 120, 2 — PP + 10 % of BK 40/90, 3 — PP + 20 % of CB 120, 4 — PP + 20 % of BK 40/90

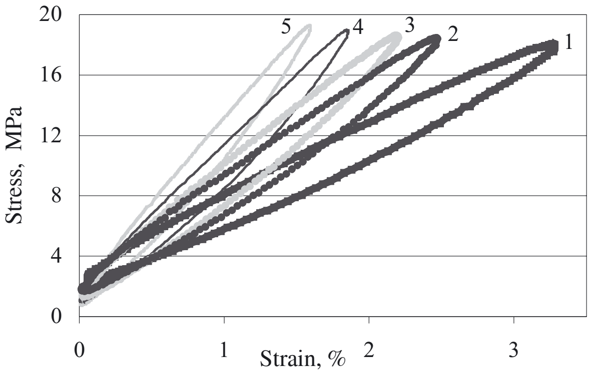

Fig. 5. Examples of hysteresis loops of PP composites with two different types of wood flour (first cycle): 1 — PP, 2 — PP with 10 % of BK 40/90, 3 — PP with 10 % of CB 120, 4 — PP with 20 % of BK 40/90, 5 — PP with 20 % of CB 120

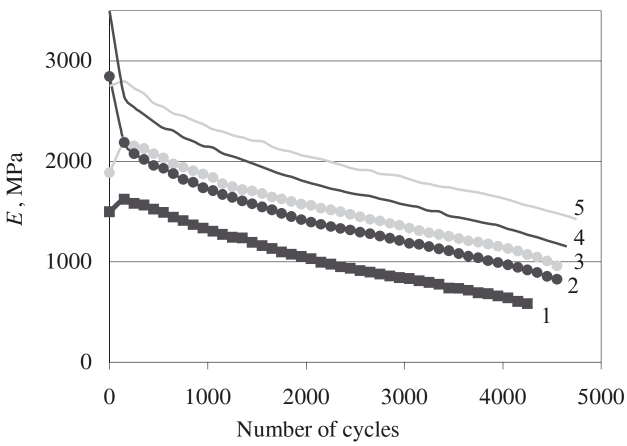

Fig. 6. Comparison of elasticity modulus (E) under cyclic loading of PP composites with two types of wood flour; for symbols — see Fig. 5

fibres (both types), elasticity modulus of investigated composites improved considerably, while strength re-

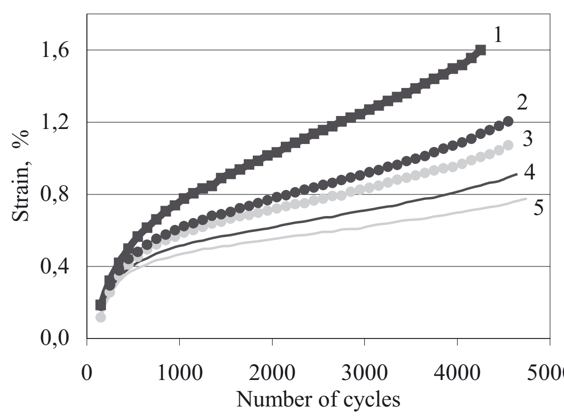

Fig. 7. Comparison of strain under cyclic loading of PP composites with two types of wood flour; for symbols — see Fig. 5

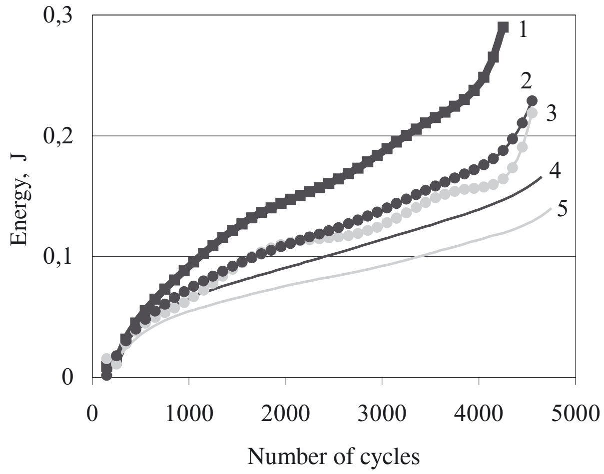

Fig. 8. Influence of wood flour on dissipation of mechanical energy of PP composites; for symbols — see Fig. 5

mained more or less constant, showing rather a marginal decrease. Elongation at break decreased significantly after adding wood fibres. Also modulus of elasticity was affected, which was about 15 % higher for PP composite with wood fibre BK 40/90.

Investigations of creep (curves 1—4 in Fig. 4) on the level of stress 12.5 MPa showed that addition of wood flour reduces the deformation being a result of long term load. When wood flour content is lower (10 %) we can observe the difference between composites with two types of wood flour: greater particles (BK 40/90, curve 2) seems to decrease elongation more then smaller (CB 120, curve 1) during long term load [9].

First stress cycles for wood fibre PP composites are shown in Fig. 5. Addition of wood flour caused decrease in elongation under cyclic load. It shows increase in ability to transfer cyclic load by composites in comparison to PP.

After adding wood fiber CB 120, the elasticity modulus of PP composites increased slightly in initial stress cycles (aprox. 200 cycles), and decreased by 50 % in final cycles. In case of PP composites with wood fibres CB 120 (smaller size of particles than BK 40/90) modulus of

a) b)

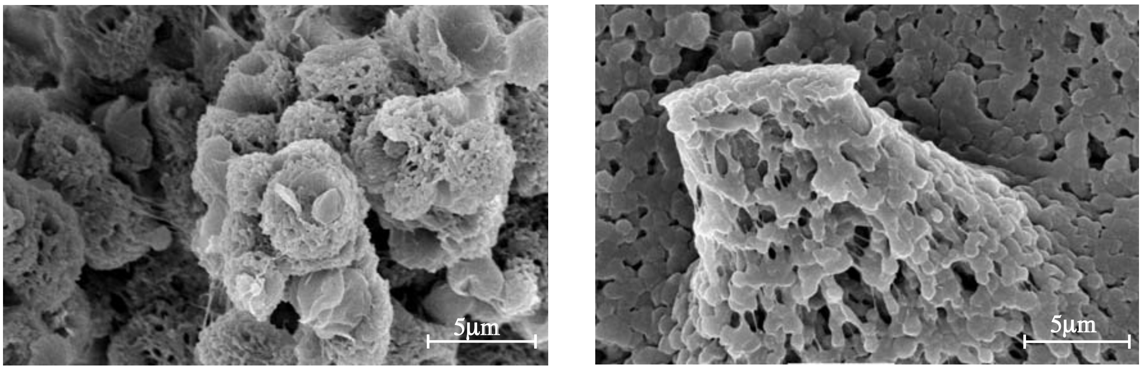

Fig. 9. SEM images: a) PP, b) single particle in polymer matrix; magnification 5000 times

a) b)

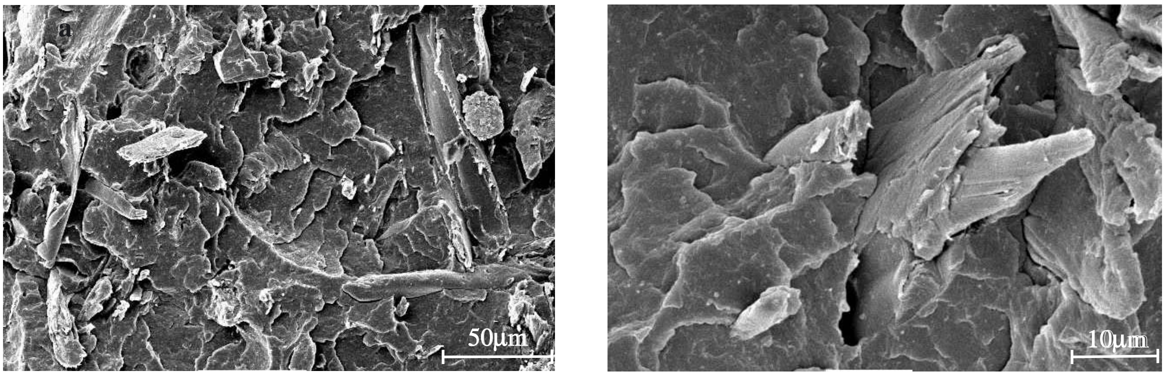

Fig. 10. SEM images of PP composites filled with 20 wt. % of wood flour (CB 120): a) magnification 500 times, b) magnification 2000 times

elasticity remained higher for both contents of wood fibres in spite of lower value at the beginning of the test (Fig. 6, curves 3 and 5). Comparison of average strain in about 5000 cycles for PP composites indicates that adding wooden filler results in decreasing intensity of dynamic creep (Fig. 7). According to Fig. 8 the ability to dissipate mechanical energy increased slightly in time (increasing number of cycles) for PP composites, however is lower for wood fibre/PP composites than for PP.

Adding wood flour to PP improved the morphology (decrease in spherulites) (Fig. 9a, b). The particles are visible all being covered with polymer matrix (Fig. 9b). Looking at the SEM images of fractures obtained at temperature of liquid nitrogen, we can observe good adhesion between polymer and the filler (Fig. 10a, b).

CONCLUSIONS

Results of tests showed that using of natural filler to modify the properties of recycled PP is possible. So, stiffness improved along with growing content of wood fibres, tensile strength remained stable and strain decreased significantly. Creep tests showed, that even adding 10 % of wood fibres decrease the strain during long term load not causing loss of strength. We could observe changes of measured properties under cyclic load: decrease in modulus of elasticity in time for all composites and increase in strain in time as effect of "dynamic creep". However adding of wood fibres to PP slowed down the negative influence of cycling load on composites' properties. PP composites with wood fibres CB 120 of smaller particles than BK 40/90 showed the best results in terms of mechanical properties under static and cyclic load.

Additional environmental benefit of using of wood fibres as the fillers could be obtained if the composites based on recycled polyolefins themselves are recycled at the end of their useful life. Finding an inexpensive, yet suitable source of waste materials, with consistent and sufficient performance can present challenges but the broad use of recycled material in wood plastic composites demonstrates its feasibility [5].

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