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EFFECT OF SCREW-DISC EXTRUSION PROCESS ON THE LEVEL OF MICROBIOLOGICAL CONTAMINATION OF WOOD-PLASTIC COMPOSITES (WPC)

The article presents the results of an analysis of the effect of the screw-disc extrusion process on the microbiological quality of WPC composites. The research material consisted of components used for the manufacture of wood-plastic composites in a form of flour, and chips from two kinds of trees (deciduous and coniferous), as well as the PP granulate and composites obtained from them. The study was conducted in two stages. Stage I involved determining the microbiological contamination level in the components used for wood-plastic composite manufacturing. Stage II involved an examination of the microbiological purity of the final composites. The composites under examination were in two forms, i.e. rods and plates. The composites were obtained using a screw-disc extruder and molds for plate compression. The microbiological examinations were conducted according to the standard PN-EN ISO 21527-1:2009. It was observed as a result of the analysis performed that the wood waste used for the production of wood-plastic composites demonstrated strong microbiological contamination, unlike the original polymer material used in the composites matrix. Irrespective of the kinds and forms of the chips used (tree species, degree of pulverization and share), the applied extrusion parameters (temperature and pressure) caused the sterilization of the obtained composites. It may be concluded that the problems presented in the literature, related to an occurrence of molds and fungi on WPC elements used outside, are the result of secondary contamination.

Keywords: screw-disk extrusion, wood-polymer composites, microbial contamination

Introduction

Wood and its derivatives are included in those materials susceptible to environmental degradation which is mainly caused by microorganisms, UV-light, as well as by the activity of wood pests (wood beetles, termites, wood wasps and others). Because of their application (terrace decking, fences, roof truss, park

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infrastructure elements, small garden architecture, etc.), wooden elements are susceptible to moisture activity, which in the case of the absence of protection creates suitable environmental conditions for the development of microorganisms (wood-destroying fungi and molds) contributing to wood decay [Sanchez-Silva, Rosowsky 2008]. The list of fungi occurring on wooden constructions is long, thus the biological corrosion of materials constitutes a considerable problem. The most commonly observed species include: *Serpula lacrymans*, *Coniophora puteana*, *Antrodia sinuosa*, *Paxillus panuoides*, *Antrodia serialis* and *Daedalea quercina* [Grzywacz 1997]. Other mold species on wood include primarily: *Alternaria alternata*, *Aspergillus flavus*, *Aspergillus ochraceus*, *Aspergillus versicolor*, *Cladosporium cladosporioides*, *Cladosporium herbarum*, *Penicillium chrysogenum*, *Penicillium velutinum* and *Penicillium waksmani*. The type of wood decay caused by fungi may be brown, white and grey. The most dangerous fungi in the first group include *Serpula lacrymans* or *Coniophora puteana*, which due to the *cellulolytic* enzymes produced decompose light, fibrous cellulose into monosaccharides. In the second group, the most expansive are *Polyporus hispidus* fungi, which secrete *ligninolytic* and *cellulolytic* enzymes, which as a consequence cause the white colour of decomposed wood. In the third group, the grey colour of decomposed wood is the result of the destruction of the structural components as well as cellulose decomposition, mainly in the wood surface layers. The fungus responsible for this phenomenon is *Chaetomium globosum* [Witomski 2005].

It is worth emphasising that the fungi inhabiting inorganic materials secrete compounds causing chemical corrosion processes, and fungi developing on organic origin materials collect nutrients from them causing their decomposition. It is also important in the human health safety context, that numerous fungi secrete toxic substances, such as endotoxins, enterotoxins, enzymes, and groups of mycotoxins [Flaninngan 1992; Janińska 2002]. Therefore, wood requires the application of arduous and costly maintenance treatments (impregnation and painting).

An alternative to wood are increasingly popular elements manufactured from wood-plastic composites. They are characterized by good mechanical properties and also a high susceptibility to traditional processing methods used in the case of wood (sawing, drilling, and cutting) [Wilkowski et al. 2013].

Wood-plastic composites are made of wood waste and polymer matrix, which may include recycled materials [Mirowski et al. 2010; Tomaszewska, Zajchowski 2013] and primary materials. The share of wood used for WPC manufacturing may contain sawmill waste, shredded woodwork and wood swarfs in a form of flour, or various size chips. Wood waste is characterized by a high level of contamination, mainly environmental [Witomski 2005]. The processes accompanying WPC manufacture (temperature, pressure) may favour an inactivation of microbiological contamination, both of the wood share and recycled polymer materials.

Literature presents reports describing the results of the degradation of elements made of WPC composites (wall and terrace panels) affected by external

factors, which may result from the primary contamination of the WPC components or a secondary one resulting from exploitation [Rowell 2006; Weinfurter, Eder 2009].

The aim of the study presented in this article is to determine changes in the microbiological contamination level in materials used for the manufacture of WPC caused by the parameters of the screw-disc extrusion process.

Research materials and methods

The research material consisted of pulverized chips of coniferous trees of Lignocel C 300 (A type chips) and Lignocel 3–4 type (C type chips), as well as chips from deciduous trees of Lignocel 150–500 (B type chips) and RaucherGold class 1–4 type (D type chips) purchased in Rettenmaier and Söhne GmbH+Co. KG company from Germany (fig. 1), and also polymeric material PP (polypropylene), type Moplen HP 456J manufactured by Basell Orlen Poliolefins sp. z o.o, and wood-plastic composites (WPC) manufactured from these materials.

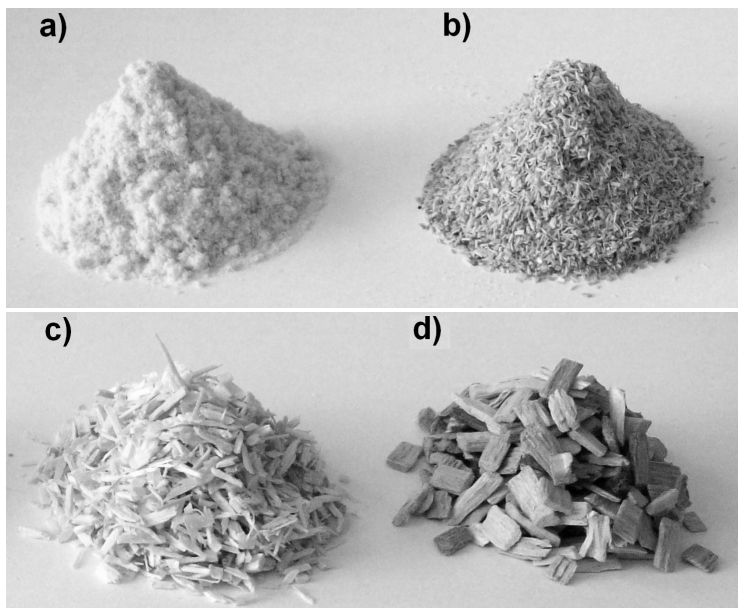


Fig. 1. View of samples for testing phase I: a) the type of conifer shavings Lignocel C 300 (wood shavings type A), b) the type of leafy tree shavings Lignocel 150–500 (wood shavings type B), c) the type of conifer shavings Lignocel 3–4 (wood shavings type C), d) the type of leafy tree shavings RaucherGold kl. 1–4 (wood shavings type C)

The wood material and PP granulate were stored in open bags in normal storage conditions for approximately 24 months. The aim of this kind of storage was to obtain the actual conditions of wood waste and recycling material storage.

Fig. 2 presents the granulometric composition of the applied chips, while the bulk density for particular chips was as follows: type A – $\rho = 261.5 \text{ kg/m}^3$, type B – $\rho = 252.5 \text{ kg/m}^3$, type C – $\rho = 116.0 \text{ kg/m}^3$ and type D – $\rho = 305.5 \text{ kg/m}^3$.

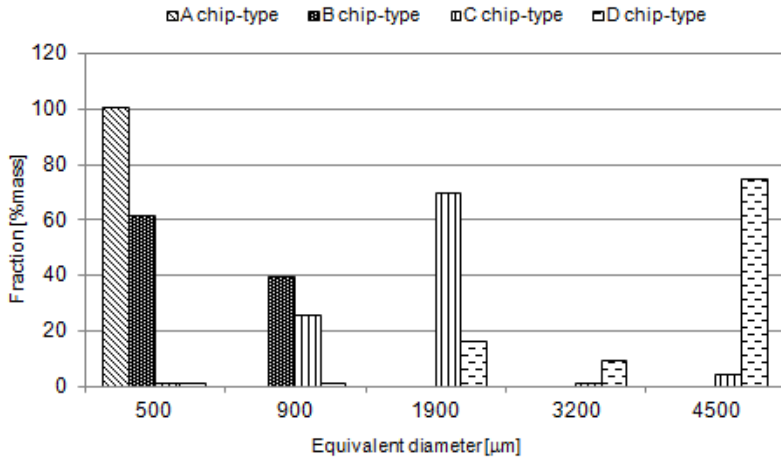


Fig. 2. Granulometric composition of applied chips type: A, B, C and D

Technology of composites production

The research site for the WPC composite production was a screw-disc extruder (fig. 3).

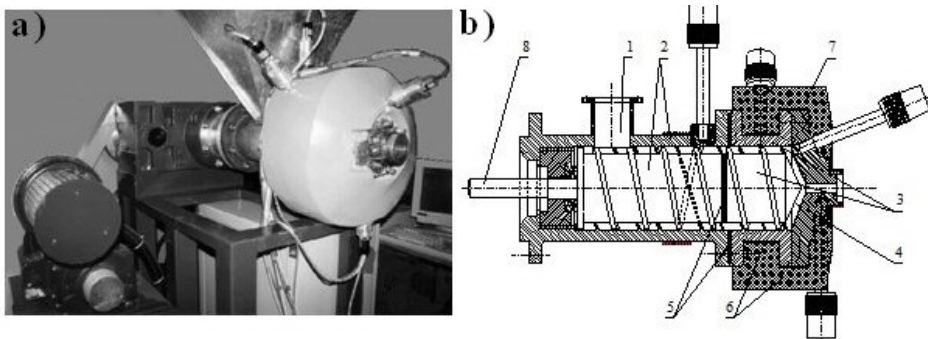


Fig. 3. Test bench – screw-disc extruder: a) general view, b) longitudinal section of plasticizing system: 1 – feed hopper, 2 – cold zone of the screw and barrel, 3 – hot zone of the screw and barrel, 4 – the chink, 5 – insulation spacers, 6 – electric heaters, 7 – thermal insulation, 8 – drive shaft [Rydzkowski, Michalska-Požoga 2014]

Extrusion parameters:

- rotational speed $n = 26 \text{ rpm}$,
- hot zone temperature $t = 200^\circ\text{C}$,

- chink width $s = 1$ mm,
- time of residence in the plasticising system $T = 90$ s.

The samples in the form of rods were obtained directly from the extrusion head, and they were further freely cooled in air.

Following this, in order to obtain the composite plates, after moving the plasticizing system of the screw-disc extruder, the fragments of the extrudates were placed between two flat plates made of stainless steel with a thickness of 40 mm, equipped with a heating (regulated temperature) and cooling system, and then a load of approx. 100 kN was applied using a hydraulic cylinder. After sample pressing to the established thickness, the system was cooled.

Research methods

The study was conducted in two stages:

- in stage I of the microbiological examinations, the wood samples in a form of flour and chips before the extrusion process (fig. 1abcd), as well as polymer material in the form of polypropylene granulate used as a matrix, were the subject of evaluation,
- in stage II of the microbiological examinations, the WPC composites obtained using selected types of chips: type B (fig. 4b) and C (fig. 4a.) with their differing shares (10 and 35%) were the subject of evaluation.

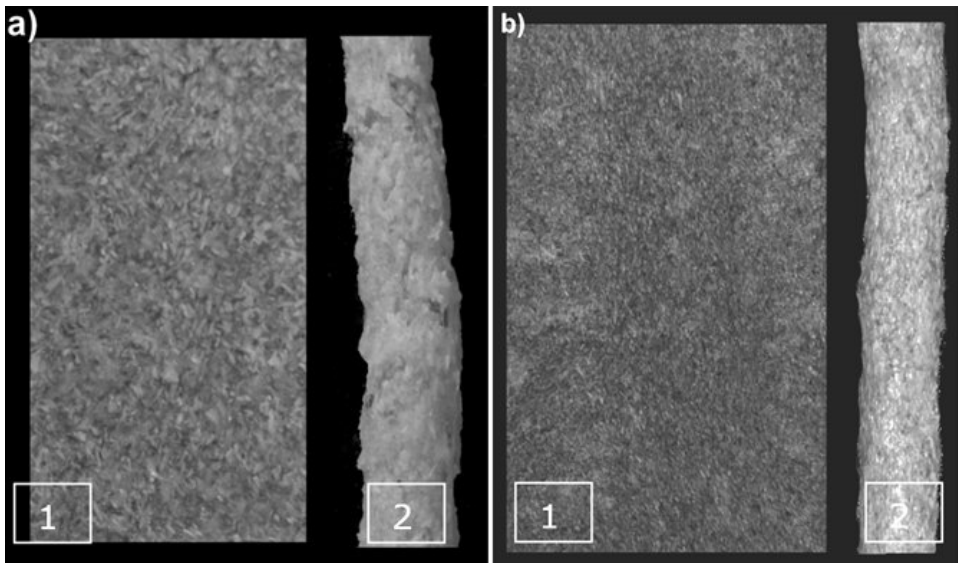


Fig. 4. View of samples for testing phase II: a) composites in the form of rods (2) and plates (1) obtained from the C-type shavings with a polypropylene matrix, b) composites in the form of rods (2) and plates (1) obtained from the B-type shavings with a polypropylene matrix

The samples for microbiological examinations in stage I and II were collected in sterile flasks to maintain the required sterile conditions. In the first, and also in the second stage of the study, 10^{-1} dilutions were made in sterile distilled water and the washings were inoculated using Koch's deep inoculation method. Fungi were cultured on Sabouraud medium with chloramphenicol.

The identification of the mold fungi was conducted based on the macro- and microscopic features of the morphological structures, such as: structure of hyphae, sporangia and spores, as well as the conidial system, conidiophores or conidial spores. The bioMerieux ID 32C test was used to identify the cultured yeasts.

The study was conducted according to the standard PN-EN ISO 21527-1:2009.

Results and discussion

On analysis of the results of stage I (table 1), quite large quantitative and species differences among the cultured fungi were observed. The detected fungi are not typical for wood waste but for storage facilities and pests. In term of quantity, the highest number of microorganisms were cultured in the chips of type C (3.2×10^2 cfu/g), and the lowest in type A (0.4×10^1 cfu/g). In turn, with regards the species differentiation of the microorganisms, the most differentiated were the chips of type B (fig. 5a plate B), where *Penicillium digitatum*, *Penicillium expansum*, *Mucor mucedo*, and *Rhodotorula rubra* were identified, and the least differentiated were the chips of type D (fig. 5a plate D), where only *Penicillium glaudicole* was noted. The examined chips were characterized by a varying degree of pulverization (fig. 1) and were derived from various tree species. The degree of fineness in the case of chips A and B was higher compared to C and D, and the contamination of C and D was higher. The tree species that the chips were derived from did not affect the number of identified microorganisms. No microorganisms were identified on material used for the matrix (granulate PP) (fig. 5b).

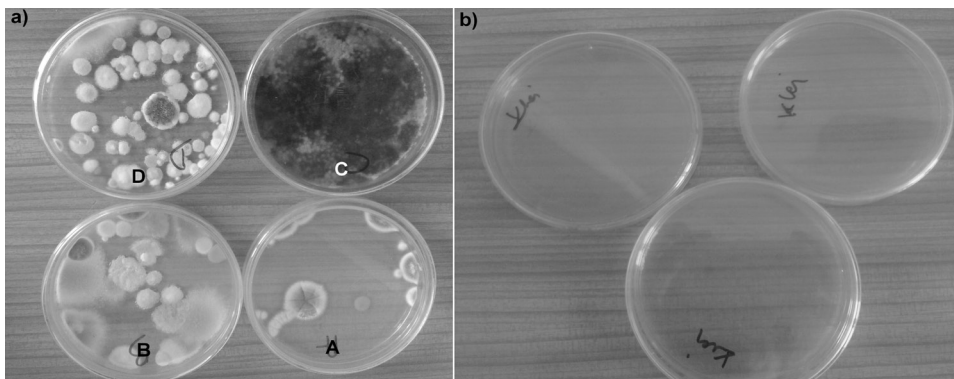


Fig. 5. Fungal growth on the substrate in the first stage of the study: a) view of the shavings type: A, B, C and D, b) view for the material used in the matrix (PP)

Table 1. Results of phase I the number of cultivated species of fungi

No.	Research material	Number of cultivated mushrooms [cfu/g]	Species of fungi
1.	A chip-type	0.4×10^1	<i>Penicillium chrysogenum</i> , <i>Rhodotorula rubra</i>
2.	B chip-type	2.6×10^1	<i>Penicillium digitatum</i> , <i>Penicillium expansum</i> , <i>Mucor mucedo</i> , <i>Rhodotorula rubra</i>
3.	C chip-type	3.2×10^2	<i>Penicillium citrinum</i> , <i>Mucor racemosus</i>
4.	D chip-type	4.0×10^1	<i>Penicillium glaudicole</i>

On analysis of the four types of chips in this study, a high differentiation in fungi species was noted, which rather proves contamination originating from the environment of the examined samples, not the trees inhabited by fungi which were dangerous for them. In particular the presence of *Rhodotorula rubra* is evidence that this is secondary contamination, which presumably occurred during technological processing. The other fungi identified inhabit various environments and may also have been transferred to the samples by insects or rodents. These fungi contribute to wood destruction, which should be prevented by the application of suitable chemical agents (impregnates).

It was noted after completing stage II of the study that the samples obtained of wood-plastic composite, irrespective of the wood species, pulverization degree and weight share in the composite, were free from all kinds of fungi and molds (table 2).

No growth of fungi and mold colonies was observed on analysis of photographs (fig. 6) presenting Petri dishes with inoculations of the examined composite washings after the incubation period.

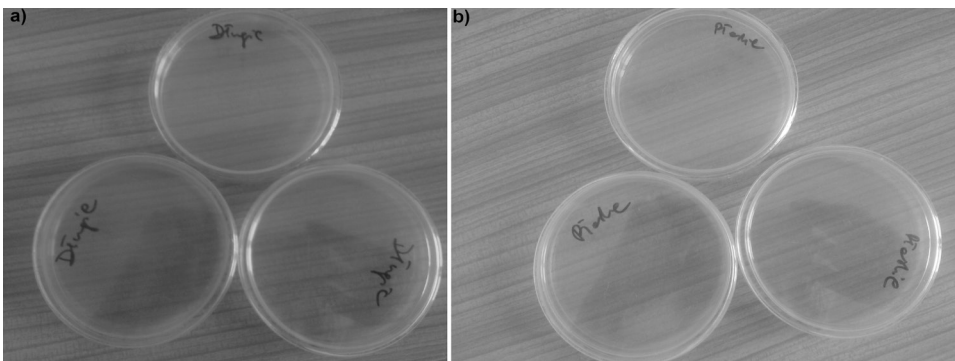


Fig. 6. Results of phase II of microbiological tests: a) for the composites in the form of rods obtained from shavings B-type and C-type of the polypropylene matrix, b) for the composites in the form of shavings obtained from plates obtained from shavings B-type and C-type of the polypropylene matrix

Table 2. Results of phase II the number of cultivated species of fungi

Research material	Number of cultivated fungi [cfu/g]	Species of fungi
Form composite WPC a) rods b) plates	0	–

Conclusions

1. The study conducted demonstrated the strong microbiological contamination of the wood waste used in wood-plastic composite manufacturing.
2. The fungi species detected in the wood waste were not typical for wood but for storage pests and facilities.
3. Primary (virgin) polymer material used for the WPC composites matrix did not exhibit any microbiological contamination.
4. Composites obtained as a results of extruding, irrespective of kinds and forms of chips applied (tree species, pulverization degree and weight share) were free from molds and fungi.
5. Applied extrusion parameters (temperature and pressure) in combination with the time of residence in the plasticising unit caused the sterilization of the materials obtained.
6. Based on the study conducted, it was concluded that the problems presented in the literature related to the occurrence of molds and fungi on WPC elements used outside, result from their secondary contamination, since after processing the composites are microbiologically pure.

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List of standards

- PN-EN ISO 21527-1:2009** Microbiology of food and animal feeding stuffs. Horizontal method for the enumeration of yeasts and moulds. Part 1: Colony count technique in products with water activity greater than 0.95