Acta Sci. Pol.
Architectura 18 (2) 2019, 11–20
ISSN 1644-0633 eISSN 2544-1760 DOI: 10.22630/ASPA.2019.18.2.17
acta_architectura.sggw.pl

ORIGINAL PAPER

Received: 26.02.2019
Accepted: 11.06.2019

IMPACT ASSESSMENT OF THE MUNICIPAL SOLID LANDFILL ON ENVIRONMENT: A CASE STUDY

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ABSTRACT

Landfilling is a method for disposal of waste. Impact of landfills on the environment is currently a crucial topic and attracted increased attention recently because they are sources of potential risks and environment pollution. Apart from the pollution risk to both surface and underground water, realistic is also the contamination of soils. The main purpose of the present study was to analyse the influence of landfills on the environment. The conducted research was focused on the assessment of the toxicity of leachates and soils in the managed municipal solid waste landfill in Těmice (the Czech Republic). Research results showed the soil collected from the active landfill body exhibited higher toxicity as compared with the samples taken from the outside of waste storage activities. Leachates from the landfill exhibited phytotoxic effects and this is why they have to be considered and handled as the wastewater.

Key words: final disposal of waste, landfill, waste water, environment impact, landfill surrounding

INTRODUCTION

The continuous development of human population brings large production of wastes and challanges with their management and disposal (Adamović, Antanasijević, Ćosović, Ristić & Pocajt, 2018; Chen, 2018). As to waste disposal, it is important that waste does not originate at all or is reused, recycled, used for energy generation or disposed. Moreover, current procedures in waste management (WM) are strongly affected by the "hierarchy of waste", which recommends priority order from the most advantageous option of "prevention" at the top to the least preferred option of "waste disposal" at the bottom (Gharfalkar, Court, Campbell, Ali & Hillier, 2015).

The most frequent method used for waste disposal in the Czech Republic is landfilling. Landfilling is a method for continuous disposal of waste in the landfill where it is subsequently compacted and covered with the material preventing it from dusting and odours. This method of waste disposal is one of cheaper and simpler options of waste disposal. What is more, disposal of waste in landfills remains the most practical and most spread solution for handling waste in most countries of the European Union, including the Czech Republic, the reasons being technical, economic and legislative (Brennan et al., 2016).

The municipal solid waste (MSW) landfills can affect their surroundings (Hoogmartens, Eyckmans & Van Passel, 2016). Landfilling impairs landscape character and is responsible for the introduction of undesirable substances into the environment. Major emissions (leachates and biogas) are considerably influenced by biological processes occurring in landfills (Scheutz &

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Kjeldsen, 2019). Landfill leachates may contain heavy metals (HM) and represent a potential risk of the pollution of soils, groundwater, plants etc. (Gworek et al., 2016). One of problems most often occurring worldwide is exactly the contamination of the soil environment (Radziemska, Gusiatin & Bilgin, 2017).

About 80% of the global production of MSW is stored in landfills. Only 20% of this amount is contained in engineered and controlled landfill sites (Caicedo-Concha, Sandoval-Cobo & Whiting, 2016). It is important to ensure appropriate landfill management and regular monitoring so that the undesirable substances are not transferred into other components of the environment. If the landfill management and safety is poor, there is a risk of waste flying away into the surroundings, bad odours, dustiness, and overpopulation of rodents, in worse cases landfill gas leakages or seepage into the environment (Koda, Mniszkowska & Sieczka, 2017). Moreover, the unpleasant odours, fires and explosions, damage to vegetation, air, soil and groundwater contamination, are widespread (Koda, Pachuta & Osiński, 2013). In the literature, evaluation of the impact of landfills on the environment (Fig. 1) is currently a crucial topic and attracted increased attention recently with respect to ecological interests.

In the Czech Republic, the establishment of new landfills is not permitted, and the existing landfills can be only extended. In addition, the current Czech Waste Management Plan (CWMP) sets up clear goals for the reduction of landfilled waste amounts. From 2024, landfilling of reusable and recycleable waste will be prohibited. The aim is to increase considerably the fee for waste disposal in landfills and thus to reduce the amount of waste usually ending in landfills. Waste can be used as a valuable raw material thanks to which the primary resources can be saved. The Czech Republic is still a great landfilling power, having one of the lowest fees in EU for landfilling the communal waste.

The main purpose of this study was to analyze the influence of selected landfill on the environment. The research goal was (i) to determine inhibition of white mustard (*Sinapis alba* L.) growth on leachate waters from a selected MSW landfill and (ii) to perform tests of soil toxicity by means of Phytotoxkit.

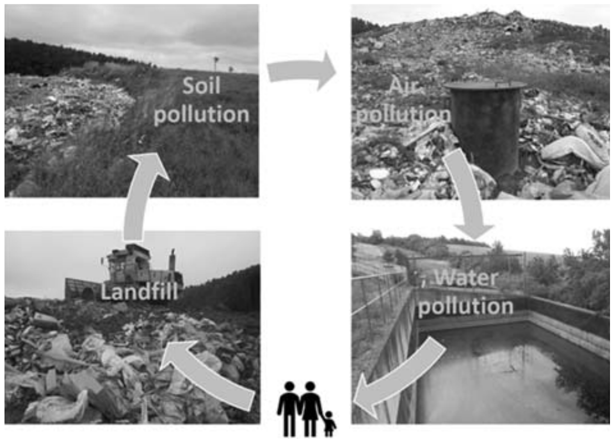

Fig. 1. Impact of landfills on the environment

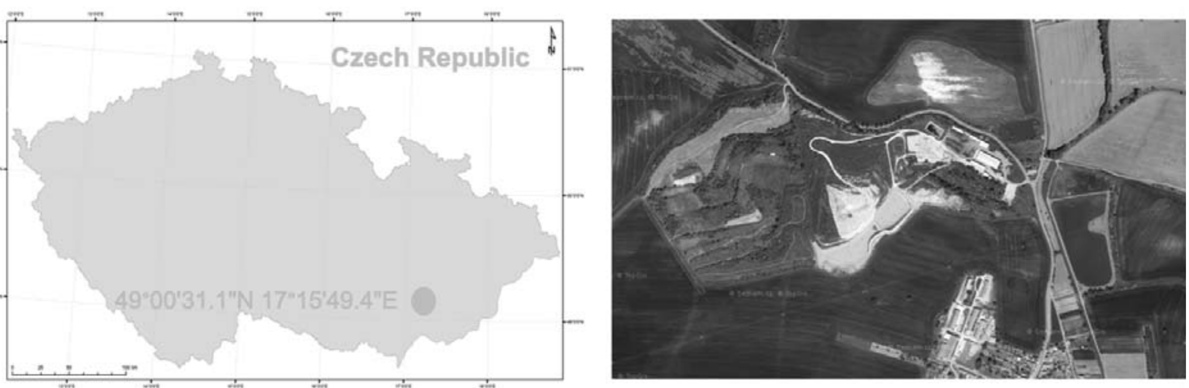

Fig. 2. Localisation of municipal solid waste landfill

MATERIAL AND METHODS

Characterization and localization of the solid communal waste landfill in Těmice

The managed MSW landfill in Těmice (49°00'31.1" N, 17°15'49.4" E) is situated in a relatively densely inhabited part of the Hodonín district in the South-Moravian Region, ca. 1 km NE of Těmice commune on the left side of Road III/4225 in the direction of Žeravice, in the track called U Fibingerova mlýna (Fig. 2). First inhabited house in Těmice is at a distance of some 650 m from the landfill. Westwards of the landfill, there is the commune of Žeravice (1.75 km), while Syrovín is northwards and Domanín (1.3 km) eastwards of the landfill. The landfill owner and operator is EKOR s.r.o. company limited, based in Kyjov (Walachová, 2017).

Natural conditions of landfill site

Morfological conditions

The landfill is part of the Kyjovská pahorkatina (Hilly Land) with the erosionally-denudation topography. The landfill site is a horizontally and vertically articulated slope of north-western aspect, the landfill foot altitude is 200–205 m a.s.l., with height elevation of the relief being ca. 65 m and slope gradient 8–10° – terrace modelation.

Geological and geotechnical conditions

The landfill area belongs to the Vienna Basin formed by Tertiary sediments with the Quaternary cover. The Tertiary sediments consist largely of a mixture of powdery sands and calcareous grey clays. The Quaternary sediments are formed by blown sands, loess loams and sandy-clay alluvial loams. The landfill is located in the area of Neogene tectonic fallouts where gully erosion is the most widespread phenomenon. Results from the monitoring of slope deformation process and the movement of the Earth's surface are minimal.

Hydrogeological and climatic conditions

The landfill subsoil consists of Pliocene sediments of variable powdery sand nature with clay components and can be characterized by low permeability and great thickness. According to Quitt (1971), the territory belongs to the warmest area of the Dolnomoravský Úval (Graben). It falls into the T4 climatic unit with very long, warm and dry weather, short and warm spring and autumn, and short, relatively warm and dry winter with the short duration of the snow cover (Table 1).

Table 1. Characterization of the T4 climatic region according to Quitt (Quitt, 1971)

Specification	Value
Number of summer days	60–70
Number of days with average temperature ≥ 10°C	170–180
Number of frost days	100–110
Number of ice days	30–40
Average temperature in January	–2°C
Average temperature in April	9–10°C
Average temperature in July	19–20°C
Average temperature in October	9–10°C
Average number of days with precipitation of minimum 1 mm	80–90
Total precipitation amount in growing season	300–350 mm
Total precipitation amount in winter period	200–300 mm
Number of days with snow cover	40–50
Number of overcast days	50–60
Number of clear days	110–120

Basic data about the landfill

The managed MSW landfill in Těmice is a technically secured landfill constructed for the disposal of wastes classified to the category of "other" waste (group S-OO, sub-group S-OO3), namely communal wastes produced in the area of Hodonín and Uherské Hradiště. The first stage of the landfill was put into operation based on the occupancy permit issued in 1996. The second stage was commissioned in 1998 (poud for leachates of second stage). The construction of the fifth stage of the landfill was launched based on the zoning permit on the location of the structure issued in 2012 (Table 2).

Landfill operation facilities

The landfill site is fenced with wire mesh up to the height of 2 m. Near the entrance into the premises, there is an operational-social building serving for the fulfilment of socially-hygienic demands. Other structures occurring on the site are the gatehouse and the electronic bridge weight (weighing capacity 60 Mg) (Vašíček, 2013).

Table 2. Basic data about the landfill (Vašíček, 2013)

Specification	Data
Landfill name	Těmice managed landfill – second part of Stage II and first structure of Stage V
Landfill category	landfill of S-OO group, S-OO3 sub-group with a possibility of azbest waste disposal, with S-OO1 sector
Landfill owner and operator	EKOR s.r.o., Havlíčkova 181, 697 01, Kyjov
Consent to operation issued by	South-Moravia Regional Authority
Landfill capacity (Stage II)	460,000 m^3, leachate class IIa
Landfill capacity (Stage V)	362,553 m^3, leachate class IIa

The drainage system and leakage sewerage system of Stage II are formed by the drainage layer of gravel and sand. In the gravel layer, perforated piping made of high-density polyethylene (HDPE) is placed. The leakage sewerage is in two HDPE branches in a total length of 150 m, which are connected to the main collector, the length of which is 35 m. The piping is not perforated through the terrestrial landfill body and its route includes four shafts.

The collecting poud of Stage II is a terrestrial, open poud without outflow sized 15 × 35 m, with a depth of 3 m and capacity of 2,500 m^3. The poud is sealed with the HDPE film. Its floor and side slopes are provided with concrete blocks. The leachates are withdrawn by means of mobile sludge pump (FLYX 60 $l \cdot s^{-1}$) and led via stable piping onto the dam crown. They are brought to the external waste water treatment plant (WWTP) and analyzed twice a year (spring/autumn) by the accredited laboratory (Vašíček, 2013).

The sewage system of landfill waters serves for the repumping of accumulated leachates from the collection well of Stage I into the sewage system and then into the collection poud of Stage II. The sewage system has a discharge part (ending in the shaft) and a gravitational part (opening from the shaft into the collection poud of Stage II).

Wells for landfill gas collection are installed on the concrete foundation and are gradually elevated in dependence on landfill filling. The landfill gas-tightness is ensured by waste compaction, coverage of aerial slopes with the technological and biologically active material as well as by degassing wells sealed with the compacted clay. The open ends of the piping are provided with gas-tight plugs and in addition, the piping is wrapped in a shrink foil. There are altogether eleven degassing wells in the landfill, of which eight are connected to the combustion cogeneration unit (Vašíček, 2013).

Furthermore, there is a composting plant, a sorting line and a site for the recycling of construction waste.

Test of white mustard (*Sinapis alba* L.) growth inhibition on leachates

Sampling of leachates

Leachates were sampled in April, May, June and July 2016. Individual samples were taken from the leachate poud (Fig. 3) and placed in sampling vessels that were at all times sterile.

After the sampling, the vessels were properly labelled to inform about the place, month and year of sampling. The samples were subsequently assessed and/or frozen. Tests of semichronic toxicity with the seeds of white mustard (*Sinapis alba* L.) were performed and evaluated in laboratories of the Department of Landscape and Applied Ecology at Mendel University in Brno.

Purpose and principle of the test

The test serves to verify toxicity of leachate that could be used for irrigation of field plants. The aim was to determine the effect of leachate on the germination of seeds and growth of roots in white mustard (*Sinapis alba* L.). The principle of the test consisted in the cultivation of seeds placed on mats saturated with leachate of certain concentration and in the comparison with

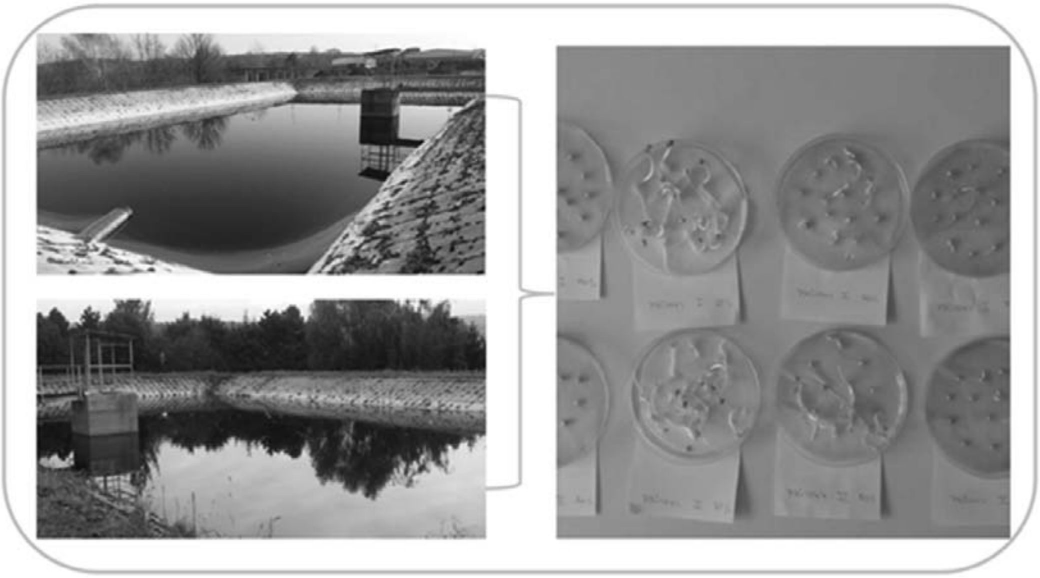

Fig. 3. Leakage well and semi-chronic toxicity test in laboratory conditions

seeds growing on mats saturated with dilution water – nutrient solution (Koči, Rakovický & Švagr, 2001).

Characteristic of white mustard (*Sinapis alba* L.)

White mustard (*Sinapis alba* L.) originates from North Africa and and is classified in the family of cruciferous plants (*Brassicaceae*). It is annual flowering oilseed plant. Its stem is hairy, upright, with green leaves. Flowers grow from the bottom and form organised inflorescences. Fruits of this plant are short pods. Yellowish seeds are of spherical shape. Simple roots growing out from the germinated seed has a subsoil segment connecting the root with the stem (Koči, Rakovický & Švagr, 2001). White mustard (*Sinapis alba* L.) is a modest plant in terms of climatic conditions and soil quality. Its advantage is rapid growth and development already in the eighth week after sowing.

Workflow

Tested leachate samples and the nutrient solution were used at diverse concentrations. Reserve solutions of salts presented in Table 3 were used in preparing the dilution water. Individual conditions of the toxicity test with the white mustard (*Sinapis alba* L.) are presented in Table 4.

Individual Petri dishes (Fig. 3) were labelled and subsequently filled with 5 ml of diverse concentrations of nutrient solution and leachate by pipetting (Table 5). Then, filter paper was placed into each Petri dish so that it completely covered its bottom and did not form air bubbles. White mustard (*Sinapis alba* L.) seeds were put onto filter paper. The Petri dishes were then closed and placed in the thermostat at a temperature of 25°C for 72 h. After 72 h, the samples were taken out and the root length was measured to calculate growth inhibition.

Table 3. Reserve solutions of salts for tests with white mustard (*Sinapis alba* L.) seeds (Koči, Rakovický & Švagr, 2001)

Nutrient solution	Chemicals	Concentration in stock solution [g·l^{-1}]
ZR 1	$CaCl_2 \cdot 2H_2O$	117.6
ZR 2	$MgSO_4 \cdot 7H_2O$	49.3
ZR 3	$NaHCO_3$	25.9
ZR 4	KCl	2.3

The testing was conducted for four months (April, May, June and July 2016) as mentioned at the beginning of the chapter.

Test evaluation

After 72 h, the Petri dishes were taken out of thermostat and root length was measured in all plants. The

Table 4. Conditions of the toxicity test (Kočí, Rakovický & Švagr, 2001)

Specification	Data
Test plant	white mustard (*Sinapis alba* L.)
Color	oak-yellow
Medium size	1.5–2 mm
Germination minimum	90%
Number of seeds in one Petri dish	15
Response	root elongation
Repetition	1
Volume of test concentration	5 ml in one Petri dish
Temperature	25°C
Exposure time	72 h
Lighting	none, in the dark
Chemicals	liquid solution, samples of leachate water
Devices and equipment	Petri dishes, filter paper, tweezers, volumetric flasks, pipettes, thermostat, millimeter scale; individual Petri dishes were labeled

Table 5. List of samples, their labelling, amount and concentration

Sample	Label	Amount
100% NS	100% NS 1 100% NS 2	5 ml NS
100% LL	100% LL 1 100% LL 2	5 ml LL
90% LL	90% LL 1 90% LL 2	4.5 ml LL 0.5 ml NS
75% LL	75% LL 1 75% LL 2	3.75 ml LL 1.25 ml NS
50% LL	50% LL 1 50% LL 2	2.5 ml LL 2.5 ml NS
25% LL	25% LL 1 25% LL 2	1.25 ml LL 3.75 ml NS

Nutrient solution (NS), landfill leachate (LL).

measured values served to calculate the arithmetic mean of root length in all repetitions. Based on these mean lengths, growth inhibition was calculated for the respective concentrations according to the following formula:

$$I = \frac{D(k) - D(t)}{D(k)}$$

where:
I – root growth inhibition [%],
$D(k)$ – mean root length in the control [mm],
$D(t)$ – mean root length in the tested concentration [mm].

The resulting values showed growth inhibition or stimulation of white mustard seeds.

Test of soil phytotoxicity conducted by using Phytotoxkit

The second test conducted was the test of soil toxicity made by using the Phytotoxkit. The seeds of white mustard (*Sinapis alba* L.) were used. The tests were conducted and evaluated in the laboratories of the Department of Landscape and Applied Ecology, Mendel University in Brno. The Phytotoxkit measures decreased (or restricted) seed germination or root growth after three days of the exposure of selected higher plants to toxic substances or contaminated soil. Apart from the evaluation of the toxicity of contaminated soils, the Phytotoxkit is also useful to assess toxicity of sludges, sediments, composts or wastewaters.

Soil sampling

Soil samples were collected from the MSW landfill Těmice in 2016. There were altogether six samples taken from different places of the landfill site (Fig. 4).

The samples were brought to the laboratory of the Department of Landscape and Applied Ecology, Mendel University in Brno where the phytotoxicity tests were conducted with the aim to determine the growth inhibition percentage. The soil samples were dessicated to constant weight, sieved through a two-milimeter sieve and stored in darkness until the test implementation.

Fig. 4. Sampling points of soil samples and soil phytotoxicity test

Test of phytotoxicity

Toxicity of the soil samples was determined as a potential impact of landfill on the soil. The seeds of white mustard (*Sinapis alba* L.) were used in a seed germination experiment to assess the soil phytotoxicity (MicroBioTests Inc., 2004; Zhang & Sun, 2017). The Phytotoxkit makes use of flat and shallow transparent test plates composed of two compartments, the lower one of which contains soil saturated to water holding capacity. The Phytotoxkit measures the decrease (or absence) of seed germination and of the growth of young roots after three days of the exposure of selected seeds of higher plants to the contaminated matrix as compared with the controls in the reference soil (OECD soil). Water saturation is calculated according to the user's manual. Distilled water was spread over the entire soil surface in the test plate. Ten seeds of white mustard (*Sinapis alba* L.) were placed at equal distances near the middle ridge of the test plate on a filter paper placed on the top of hydrated soil samples. After closing, the test plates were placed vertically in a holder and incubated at 25°C for three days. At the end of the incubation period a digital picture was taken of the test plates with the germinated plants. The following concentrations of soil samples were tested in three replications: 25 and 50%. The analyses and the length measurements were performed using the Image Tool 3.0 for Windows (UTHSCSA, San Antonio, USA; Adamcová, Vaverková, Bartoň, Havlíček & Břoušková, 2016).

RESULTS AND DISCUSSION

Results of growth inhibition test with white mustard (*Sinapis alba* L.) on leachates

Leachates were sampled in April, May, June and July 2016. Measured values were recorded in the laboratory diary and root growth inhibition was calculated. The calculation of mean root length had to include also non-germinated seeds with the zero-root length. The resulting values indicated inhibition or stimulation of root growth. If the result was ≤ 0, the effect was stimulating and if the result was > 0, the effect was inhibiting. The higher is the value (percentage) of inhibition, the higher is the sample toxicity (Kočí, Rakovický & Švagr, 2001).

Inhibition for the individual concentrations of leachates sampled in April 2016 ranged from 10.11 to 100%. It is quite clear that the inhibition grows with the increasing concentration of leachates (Table 6), the least toxic leachate concentration for the seeds of white mustard (*Sinapis alba* L.) being 25%.

Table 6. Results of white mustard (*Sinapis alba* L.) growth inhibition on leachates in the respective months

Landfill leachate concentration	Month/Year			
	04/2016	05/2016	06/2016	07/2016
100% LL	100	97.10	97.81	94.47
90% LL	100	98.14	91.08	91.71
75% LL	99.21	93.59	87.48	82.73
50% LL	68.56	55.64	45.23	34.20
25% LL	10.11	4.34	14.08	0.52

Results of soil phytotoxicity test

Soil was sampled in May and September 2016. Measured values were recorded in the laboratory diary and root growth inhibition in white mustard (*Sinapis alba* L.) was calculated. The calculation of mean root length had to include also non-germinated seeds with the zero-root length. The resulting values (Table 7) indicated inhibition or stimulation of root growth. If the result was ≤ 0, the effect was stimulating, and if the result was > 0, the effect was inhibiting. The higher was the value (percentage) of inhibition, the higher was the sample toxicity (Kočí, Rakovický & Švagr, 2001).

Table 7. Results of testing white mustard (*Sinapis alba* L.) growth inhibition on soil samples

Sample	Concentration 50% [%]	Concentration 25% [%]
Soil 1	30.92	28.21
Soil 2	24.36	20.14
Soil 3	2.26	0.15
Soil 4	39.89	28.96
Soil 5	8.67	12.14
Soil 6	5.66	1.06

Inhibition for the respective concentrations of sampled soils ranged from 0.15 to 39.89%. In addition, the performed test of soil phytotoxicity indicated that samples collected from the landfill body (Samples 1, 2 and 4) at a concentration of 50% are more toxic and showing higher inhibition of white mustard (*Sinapis alba* L.) growth than samples taken from the outside of the active landfill body (Samples 4, 5, 6) – Figure 4. A similar situation can be observed in the concentration of 25%. It can be stated that the soil samples collected from the active landfill body exhibited higher toxicity, probably due to the composition of input waste.

In 2015, the same test of the semichronic toxicity of leachates was conducted with the seeds of white mustard (*Sinapis alba* L.) in the Štěpánovice landfill (the Czech Republic). The test of white mustard (*Sinapis alba* L.) growth inhibition conducted in the month of June 2015 revealed the following inhibition values: 42% (for the concentration of 25%), 73% (for the concentration of 50%), 97% (for the concentration of 75%), 99% (for the concentration of 90%) and 100% (for the concentration of 100%) (Grocholová, 2016).

Another test of white mustard (*Sinapis alba* L.) growth inhibition on leachates was conducted in the Kuchyňky landfill (the Czech Republic) in 2015 with the following results for root length growth inhibition in the month of July: 19.06% (for the concentration of 25%), 82.12% (for the concentration of 50%), 98.24% (for the concentration of 75%), 99.41% (for the concentration of 90%), and 99.24% (for the concentration of 100%) (Staňková, 2016).

Compared with the test of white mustard (*Sinapis alba* L.) growth inhibition conducted in the Těmice landfill in July 2016, the results of inhibition were markedly lower: 0.52% (for the concentration of 25%), 34% (for the concentration of 50%), 82% (for the concentration of 75%), 91% (for the concentration of 90%), and 94.47% (for the concentration of 100%). The highest inhibiting effects of leachates were measured in April 2016, ranging from 10.11 to 100%. By contrast, the lowest inhibiting effects were observed in July 2016, ranging from 0.52 to 94.47%.

In the research conducted by Vaverková, Zloch, Radziemska and Adamcová (2017), soils were sampled from four sites of the Kuchyňky (the Czech Republic) landfill in 2014 and 2015. The samples were taken from the reclaimed part of the landfill, from the nearest landfill surroundings and from the point in which the main road crosses the access road to the landfill site. A test of phytotoxicity was conducted in laboratory conditions with using the seeds of white mustard (*Sinapis alba* L.) and common barley (*Hordeum vulgare* L.). The soil samples from the landfill were at the concentrations of 25 and 50%. The experiment was focused on the assessment of germinating capacity. In 2014, the germinating capacity in the soil samples ranged from 100 to 111% in *Sinapis alba* L. and from 92 to 107% in *Hordeum vulgare* L. Soil samples from 2015 exhibited higher germinating capacity of the both studied plant species as well as in the both concentrations. The germinating capacity for white mustard (*Sinapis alba* L.) and barley (*Hordeum vulgare* L.) was 97–127% and 104–134%, respectively. Based on data observed by Vaverková et al. (2017), there were no toxic substances significantly inhibiting the germinating capacity or growth of the plants.

Nevertheless, it should be noted that the comparison of the results of semi-chronic toxicity by using the white mustard (*Sinapis alba* L.) from different landfills is very complicated and the results are variable, primarily depending on the composition and amount of waste stored in the landfill as well as on climatic and biological factors.

CONCLUSIONS

Landfilling remains dominant method in communal waste management and MSW landfills represent considerable interference with the landscape character. In addition, they are sources of potential risks and environment pollution. Apart from the pollution risk to both surface and underground water, realistic is also the contamination of soils in the landfill site and its near surroundings. The conducted research was focused on the assessment of the toxicity of leachates and soils in the managed MSW landfill in Těmice (the Czech Republic). Research results showed that all soil samples collected in May 2016 were growth inhibiting. As compared with samples taken from the outside of waste storage activities, soil samples collected from the active landfill body exhibited higher toxicity. Apparently, these results were affected by the composition of deposited waste as well as by activities related to waste transportation and handling. Growth inhibiting effects of leachates were influenced primarily by the composition of these leachates and also by total precipitation amounts and temperatures at the place of leachate poud. There are many factors affecting the quality of leachates, e.g. landfill age, total precipitation amount, seasonal weather fluctuations, waste types and their composition. Leachates from the landfill in Těmice (the Czech Republic) exhibited phytotoxic effects and this is why they have to be considered and handled as the wastewater.

REFERENCES

Adamcová, D., Vaverková, M. D., Bartoň, S., Havlíček, Z. & Břoušková, E. (2016). Soil contamination in landfills: a case study of a landfill in Czech Republic. *Solid Earth*, *7*, 239–247. DOI: 10.5194/se-7-239-2016

Adamović, V. M., Antanasijević, D. Z., Ćosović, A. R., Ristić, M. Đ. & Pocajt, V. V. (2018). An artificial neural network approach for the estimation of the primary production of energy from municipal solid waste and its application to the Balkan countries. *Waste Management*, *78*, 955–968. DOI: 10.1016/j.wasman.2018.07.012

Brennan, R. B., Healy, M. G., Morrison, L., Hynes, S., Norton, D. C. & Clifford, E. (2016). Management of landfill leachate: The legacy of European Union Directives. *Waste Management*, *55*, 355–363. DOI: 10.1016/j.wasman.2015.10.010

Caicedo-Concha, D. M., Sandoval-Cobo, J. J. & Whiting, K. (2016). An Experimental Study on the Impact of Two Dimensional Materials in Waste Disposal Sites: What Are the Implications for Engineered Landfills? *Sustainable Environment Research*, *26* (6), 255–261.

Chen, Y-CH. (2018). Evaluating greenhouse gas emissions and energy recovery from municipal and industrial solid waste using waste-to-energy technology. *Journal* *of Cleaner Production*, *192*, 262–269. DOI: 10.1016/j.jclepro.2018.04.260

Gharfalkar, M., Court, R., Campbell, C., Ali, Z. & Hillier, G. (2015). Analysis of waste hierarchy in the European waste directive 2008/98/EC. *Waste Management*, *39*, 305–313. DOI: 10.1016/j.wasman.2015.02.007

Grocholová, S. (2016). *Hodnocení toxicity průsakových vod ze skládky odpadů Štěpánovice* [*Evaluation of leachate toxicity from landfill Stěpánovice*] (unpublished master's thesis). Mendel University in Brno, Brno. Retrived from http://theses.cz/id/w2h9fa/zaverecna_prace.pdf.

Gworek, B., Dmuchowski, W., Koda, E., Marecka, M., Baczewska, A.H., Brągoszewska, P., Sieczka, A. & Osiński, P. (2016). Impact of the Municipal Solid Waste Łubna Landfill on Environmental Pollution by Heavy Metals. *Water*, *8* (10). DOI: 10.3390/w8100470

Hoogmartens, R., Eyckmans, J. & Van Passel, S. (2016). Landfill taxes and Enhanced Waste Management: Combining valuable practices with respect to future waste streams. *Waste Management*, *55*, 345–354. DOI: 10.1016/j.wasman.2016.03.052

Kočí, V., Rakovický, T. & Švagr, A. (2001). *Test semichronické toxicity se semeny* Sinapis alba [*Semi-chronic toxicity test with* Sinapis alba]. Praha, Vysoká škola chemicko – technologická v Praze. Retrieved form http://ekotoxikologie.sweb.cz/toxlab/vyuka/sinapis.htm#_Toc525630663

Koda, E., Miszkowska, A. & Sieczka, A. (2017). Levels of Organic Pollution Indicators in Groundwater at the Old Landfill and Waste Management Site. *Applied Sciences*, *7* (6), 638. DOI: 10.3390/app7060638

Koda, E., Pachuta, K. & Osinski, P. (2013). Potential of Plant Applications in the Initial Stage of the Landfill Reclamation Process. *Polish Journal of Environmental Studies*, *22* (6), 1731–1739.

MicroBioTests Inc. (2004). Phytotoxkit. Seed germination and early growth microbiotest with higher plants. In *Standard Operational Procedure*. Nazareth, Belgium.

Quitt, E. (1971). *Klimatickeì oblasti Czeskoslovenska* [*Climatic regions of Czechoslovakia*]. Prague: Academia.

Radziemska, M., Gusiatin, Z. M. & Bilgin, A. (2017). Potential of using immobilizing agents in aided phytostabilization on simulated contamination of soil with lead. *Ecological Engineering*, *102*, 490–500.

Scheutz C., & Kjeldsen, P. (2019). Guidelines for landfill gas emission monitoring using the tracer gas dispersion method. *Waste Management*, *85*, 351–360. DOI: 10.1016/j.wasman.2018.12.048

Staňková, J. (2016). [*Allysis of leachate toxicity from waste dumps Kuchyňky*] (unpublished diploma thesis). Mendel University in Brno, Brno.

Vašíček, L. (2013). *Provozní řád- řízená skládka odpadů Těmice* [*Operating order – controlled waste landfill Těmice*]. Final monitoring report. Kyjov.

Vaverková, M. D, Zloch, J., Radziemska, M. & Adamcová, D. (2017). Environmental impact of landfill on soils – the example of the Czech Republic. *Polish Journal of Soil Science*, *50* (1), 93–100.

Walachová, K. (2017). *Hodnocení toxicity průsakových vod a půd ze skládky odpadů* [*Assessment of leachate and landfill toxicity from landfill*] (unpublished master's thesis). Mendel University in Brno, Brno. Retrieved form http://theses.cz/id/slkrym/zaverecna_prace.pdf.

Zhang, L. & Sun, X.Y. (2017). Addition of fish pond sediment and rock phosphate enhances the composting of green waste. *Bioresourse Technology*, *233*, 116–126.

OCENA WPŁYWU SKŁADOWISKA ODPADÓW KOMUNALNYCH NA ŚRODOWISKO: STUDIUM PRZYPADKU

STRESZCZENIE

Składowanie odpadów jest jedną z metod ich unieszkodliwiania. Oddziaływanie składowisk odpadów komunalnych na środowisko przyciąga coraz większą uwagę, ponieważ składowiska odpadów mogą być źródłem zagrożeń i zanieczyszczenia środowiska. Oprócz ryzyka zanieczyszczenia wód powierzchniowych i podziemnych możliwe jest również zanieczyszczenie gleb. Głównym celem przeprowadzonych badań była ocena wpływu wybranego składowiska odpadów komunalnych na środowisko. Przeprowadzone badania koncentrowały się na ocenie toksyczności odcieków i gleb ze składowiska odpadów komunalnych w Těmicach (Republika Czeska). Wyniki badań wykazały, że gleba pobrana z aktywnej części składowiska odpadów wykazywała większą toksyczność w porównaniu z próbkami gleby pobranymi poza składowiskiem. Odcieki ze składowiska wykazywały działanie fitotoksyczne, dlatego należy je traktować jako ścieki.

Słowa kluczowe: unieszkodliwianie odpadów, składowisko, ścieki, wpływ na środowisko, otoczenie składowiska

Acta Sci. Pol.
Architectura 18 (2) 2019, 21–25
ISSN 1644-0633 eISSN 2544-1760 DOI: 10.22630/ASPA.2019.18.2.18
acta_architectura.sggw.pl

ORIGINAL PAPER

Received: 09.05.2019
Accepted: 10.07.2019

THE IMPACT OF THE LENGTH OF POLYPROPYLENE FIBERS ON SELECTED PROPERTIES OF CONCRETE

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ABSTRACT

Concrete, being one of the most important construction materials, despite many advantages (ease of handling, high compressive strength, low production cost, heat resistance) it also has many disadvantages, including low tensile strength as well as sensitivity to destructive action of chemical agents. A constant growth in expectations concerning increasing the quality of concrete led to its polymer modification, whose aim was to eliminate above-mentioned disadvantages. The scope of the present research involved designing and making of concrete mixtures modified by 6, 12 and 19 mm long polypropylene fibres. For the experiment the authors used: Portland cement CEM I 42.5R, sand, gravel aggregate of the 2–8 and 8–16 fractions, water, Master Pozzolith STD plasticizer and polypropylene fibres of various length. The authors made three series of concrete samples modified by fibres, for which the following factors have been assigned: compression strength after 7, 28 and 56 days of maturing as well as absorptivity, volumetric density and frost resistance after 100 cycles of freezing and thawing. There was also conducted the flexural tensile-strength test after 28 days of maturing of concrete samples of the particular series.

Key words: polypropylene fibers, concrete, compressive strength

INTRODUCTION

Concrete and steel are the most commonly used construction materials, which form the image of the contemporary architecture. A constant growth of the quality of these products is caused by both an increase in users' expectations and an increase in demands determined by certain regulations (Kakooei, Hazizan, Jamshidi & Rouhi, 2012; Nowicka-Skowron & Ulewicz, 2015; Ansari & Sharma, 2017). Polymers, as modifiers, have been used to improve the concrete quality for over fifty years (Chandra, 1995; Ulewicz, Selejdak, Borkowski & Jagusiak-Kocik, 2013). The group of polymer concretes include: resin concrete (PC), polymer-cement concrete (PCC), polymer impregnated concrete (PIC) (Czarnecki, 2010; Sharma & Bansal, 2016). Moreover the plastic fibers are used in concrete is to enhance the mechanical and durability properties of conventional concrete. For this purpose, both commercial fibers and obtained from waste materials are used (Wang, Wu & Li, 2000; Han, Hwang, Yang & Gowripalan, 2005; Ochi, Okubo & Fukui, 2007; Kim, Yi, Kim, Kim & Song, 2010; Karahan & Atis, 2011; Nibudey, Nagarnaik, Parbat & Pande, 2013; Gu & Ozbakkaloglu, 2016; Krupińska & Mariak, 2016). The use plastic fibers as reinforcement to replace steel fibers in concrete has ecologic and ecological benefits, because steel is expensive and susceptible to corrosion. Whereas, plastic fibers are cost-effective, have lower carbon footprint and are corrosion resistant.

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Pietrzak, A., Ulewicz, M. (2019). The impact of the length of polypropylene fibers on selected properties of concrete. *Acta Sci. Pol. Architectura 18* (2), 21–25, DOI: 10.22630/ASPA.2019.18.2.18

The plastics are used in concrete mainly in two forms: as plastic aggregates (PA), which replace natural aggregates and plastic fibers (PF), which are used in fiber-reinforced concrete (FRC) (Chen & Liu, 2004; Choi, Moon, Chung & Cho, 2005; Tang, Lo & Nadeem, 2008; Choi, Moon, Kim & Lachemi, 2009; Kan & Demirboða, 2009; Fraternali et al., 2011).

According to requirements of the standard PN-EN 14889-2:2007, polypropylene fibres are defined as straight or deformed fragments of extruded, oriented and cut polymer material, useful in homogeneous mixing with concrete or mortar. Polymers listed in the standard comprise, for example polypropylene, polyethylene, polyester, nylon, polyvinyl alcohol, polyacryl, aramid and their mixtures.

The standard classification of polymer fibres refers to their physical form.
- Class Ia – microfibers: diameter < 0.30 mm; single;
- Class Ib – microfibers: diameter < 0.30 mm; fibrillated;
- Class II – macrofibres: diameter > 0.30 mm.

A literature review shown that in laboratory both a commercial plastics fibers (according to the standard norm) and plastics wastes are used. Concrete modified by polypropylene fibres is used for making industrial flooring, road and airport surfaces, and prefabricated thin-walled elements. The main advantage of using such fibres is to prevent the occurrence of anti-shrinkage cracks in "young" maturing concrete. However, having reached the resistance designed and the modulus of elasticity such fibres cease to work. Then, the stresses are transferred by concrete itself or main anchoring bars.

Most often, in the publications the results of research on the properties of mechanical materials with the addition of polymers fibres are presented. However, there are no detailed reports on the properties of polymeric materials used and their influence on the properties of made concrete composites (Krupińska & Mariak, 2016). Therefore the aim of the paper was to determine the influence of the length of the polypropylene fibre on the basic properties of concrete.

EXPERIMENTAL

For the experiment the authors used: Portland cement CEM I 42.5R, sand, gravel aggregate of the 2–8 and 8–16 mm fractions, water, Master Pozzolith STD plasticizer and polypropylene fibres of various length (Table 1).

Table 1. Properties of polypropylene fibres used in the study

Fibre designation	Properties			
	shape	colour	diameter [μmm]	fibre length [mm]
F1				6 ±1.5
F2	round	white	34 ±5%	12 ±1.5
F3				19 ±1.5

Samples for the research were made in forms according to requirements of the standard PN-EN 12390--1:2013-03. For all series of concrete samples there were twelve 15 × 15 × 15 cm cubic samples, twelve 10 × 10 × 10 cm samples and three 15 × 15 × 60 cm beams, formed according to standard PN-EN 12390--2:2011. The experiment of durability of compressive strength was conducted after 7, 28 and 56 days of sample maturing under laboratory conditions according to standard PN-EN 206:2014. The experiment was carried out by means of the Toni Technik type 2030 testing machine according to the standard (Fig. 1).

Using direct method (PN-88/B-06250) the authors conducted a study of concrete frost-resistance for a F100 resistance class. After 28 days of maturation,

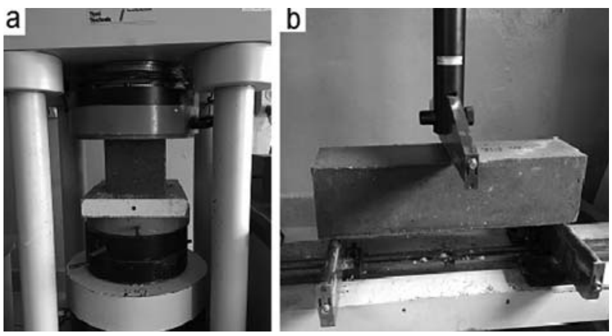

Fig. 1. Strength test on: a – compression; b – flexural tensile-strength

the frost resistance test was started according to the standard. The samples were placed in a freezer compartment where the air temperature was –18°C ±2°C. The freezing time was 4 h. After this time, samples were thawed in water at +18°C ±2°C for 4 h. This is one cycle. After the last cycle, the samples were weighed and compressed.

In this work, four series of samples were made. Control concrete sample with the w/c ratio with equal 0.55 the addition of plasticizer in the amount of 0.3% of the cement bulk – (1K) series. In the subsequent attempts the control concrete was modified with polypropylene fibres (F1–F3 series) in the amount of 0.9 kg·m^{-3}.

RESULTS AND DISCUSSION

The research results on the compression strength, absorptivity and concrete density for particular series are presented in Table 2. The average compressive strength of the control concrete series (1K) measures after 7 days equalled f_{cm} = 38.2 MPa. Adding polypropylene fibres caused a slight increase in average compressive strength for two of the modified series. After 7 days of maturing, the biggest, 3.4% increase of compressive strength in relation to the control concrete series was observed in F2 and F3 series. The 9.5% decrease, in compressive strength was examined in F1 series. The average compressive strength of the control concrete series (1K), measures after 28 days f_{cm} = 46.7 MPa. The average compressive strength, gained in F1 series, was on the similar level as in the control series and it equalled 46.7 MPa. An increase of the compressive strength in relation to the 1K series was noticed in F2 and F3 concrete series (1.7 and 4.4%, respectively).

The average compressive strength of the control concrete series (1K), measured after 56 days of maturing f_{cm} = 51.4 MPa. In all concrete series (F1 and F3) modified by fibres the average compressive strength was on the similar level as in the control series.

On the basis of the methodology included in standard PN-88/B-06250, an experiment of absorbability of particular series was conducted and the findings are presented in Table 2. According to the above-mentioned standard, the absorbability of concrete exposed to environmental influences should not be bigger than 5%. However, for concrete protected from direct weather conditions should not be bigger than 9%. Both the control concrete series and the polypropylene fibre modified concrete reached the absorbability within 5.4–5.6%.

The flexural tensile-strength test of concrete samples of particular series was conducted in accorance with the standard PN-EN 206-1:2014 and the results are presented in Figure 1. The average flexural tensile-strength of the control concrete sample (1K), measured after 28 days equalled 2.5 MPa. For the series including polimere fibres, F1–F3, there were obtained results of 2.4, 2.4 and 2.5 MPa, respectively.

Using direct method (PN-88/B-06250) the authors conducted a study of concrete frost-resistance for a F100 resistance class. The results are presented on Figure 2. The analytical determination is taken as positive if after carrying out of *n* cycles of freezing and

Table 2. Results of compression strength, absorptivity and concrete density for particular series

Concrete series	Average compression strength (f_{cm}) [MPa]			Absorptivity (n_w) [% mass]	Volumetric density (ρ) [kg·m^{-3}]	Average flexural tensile strength [MPa]
	after 7 days of maturing	after 28 days of maturing	after 56 days of maturing			
1K	38.2	46.7	51.4	5.5	2 283	2.5
F1	34.6	46.6	48.3	5.5	2 259	2.4
F2	39.4	47.5	51.5	5.4	2 260	2.4
F3	39.5	48.8	51.7	5.6	2 293	2.5

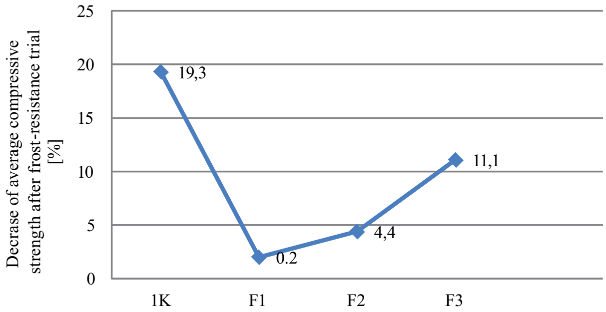

Fig. 2. Decrease of average compressive strength of particular concrete series after frost-resistance trial

thawing, required by certain frost resistance class: the average decrease of compressive strength does not exceed 20%, the average loss in mass does not exceed 5% and none of the examined samples breaks or scratches. The decrease of resistance for alternate freezing and thawing of the control series equalled 19.3%. As presented in Figure 2 the F1–F3 concrete series modified by polypropylene fibres showed much smaller decrease of resistance for alternate freezing and thawing in relation to the control series. The smallest decrease of strength after concrete frost-resistance trial was noticed in F1 series and it equalled 2.0%. For F2 and F3 series the decrease of strength equalled 4.4 and 11.1%, respectively. The loss of mass for all concrete series was in the range of between 0.11–0.39%.

CONCLUSIONS

Concrete series modified by 6, 12 and 19 mm long polypropylene fibres obtained comparable drainage durability in relation to the control series. Along with the growth of the fibre length in the range of between 6–19 mm, a slight increase in compressive strength of concrete. Series of concrete modified by polypropylene fibres demonstrated better resistance to freezing and thawing, as they obtained a smaller decrease in compressive strength in relation to the control series. The smallest decrease of compressive strength, equalling 2.0%, after frost-resistance trials demonstrated concrete samples containing fibres of 6 mm length. The length of polymer fibers did not affect the tensile strength when bending. For all the tested series it was at the level of 2.5 MPa. Also, the length of the polymer fibers used does not affect the absorbability of concrete.

REFERENCES

Ansari, S. & Sharma, H. S. (2017). Comparison of properties of Fiber Mix Reinforced Concrete and Conventional Concrete. *International Journal of Engineering Science*, 7, 12202–12205.

Chandra, S. (1995). Historical background of polymers used in concrete. In *Proceedings of 8th International Congress on Polymers in Concrete*, Oostende (pp. 3–11). Leuven: KU Leuven.

Chen, B. & Liu, J. (2004). Properties of lightweight expanded polystyrene concrete reinforced with steel fiber. *Cement* and *Concrete Research*, *34*, 1259–1263.

Choi, Y. W., Moon, D. J., Kim, Y. J. & Lachemi, M. (2009). Characteristics of mortar and concrete containing fine aggregate manufactured from recycled waste polyethylene terephthalate bottles. *Construction* and *Building Materials, 23*, 2829–2835.

Choi, Y. W., Moon, D-J., Chung, J-S. & Cho, S-K. (2005). Effects of waste PET bottles aggregate on the properties of concrete. *Cement and Concrete Research*, *35*, 776–781.

Czarnecki, L. (2010). Polymer concretes. *Cement Wapno Beton*, *77*(2), 63–85.

Fraternali, F., Ciancia, V., Chechile, R., Rizzano, G., Feo, L. & Incarnato, L. (2011). Experimental study of the thermo-mechanical properties of recycled PET fiber-reinforced concrete. *Composite Structures*, *93*, 2368–2374.

Gu, L. & Ozbakkaloglu, T. (2016). Use of recycled plastics in concrete: A critical review. *Waste Management*, *51*, 19–42.

Han, C-G., Hwang, Y-S., Yang, S-H. & Gowripalan, N. (2005). Performance of spalling resistance of high performance concrete with polypropylene fiber contents and lateral confinement. *Cement and Concrete Research*, *35*, 1747–1753.

Kim, S. B., Yi, N. H., Kim, H. Y., Kim, J-H. J. & Song, Y-C. (2010). Material and structural performance evaluation of recycled PET fiber reinforced concrete. *Cement & Concrete Composites*, *32*, 232–240.

Kakooei, S., Hazizan, M. A., Jamshidi, M. & Rouhi, J. (2012). The effects of polypropylene fibers on the properties of reinforced concrete structures. *Construction and Building Materials*, *27*, 73–77.

Kan, A. & Demirboða, R. (2009). A new technique of processing for waste-expanded polystyrene foams as aggregates. *Journal of Materials Processing Technology*, *209*, 2994–3000.

Karahan, O. & Atis, C. D. (2011). The durability properties of polypropylene fiber reinforced fly ash concrete. *Materials and Design*, *32*, 1044–1049.

Kurpińska, M. & Mariak, A. (2016). Polymer fiber reinforced concrete as an alternative to steel fiber. *Materiały Budowlane*, *2*, 42–44.

Nibudey, R., Nagarnaik, P., Parbat, D. & Pande, A. (2013). Strength and fracture properties of post consumed waste plastic fiber reinforced concrete. *International Journal of Advances in Engineering* & *Technology*, *3*, 9–16.

Nowicka-Skowron, M. & Ulewicz, R. (2015). Quality management in logistics processes in metal branch. In *24th International Conference on Metallurgy and Materials* (pp. 1707–1712). Brno: TANGER.

Ochi, T., Okubo, S. & Fukui, K. (2007). Development of recycled PET fiber and its application as concrete-reinforcing fiber. *Cement* & *Concrete Composites*, *29*, 448–455.

Ulewicz, R., Selejdak, J., Borkowski, S. & Jagusiak-Kocik, M. (2013). Process management in the cast iron foundry. In *Metal 2013: 22nd International Conference on Metallurgy and Materials*, Brno (pp. 1926–1931). Ostrava: TANGER.

Sharma, R. & Bansal, P. (2016). Use of different forms of waste plastic in concrete e a review. *Journal of Cleaner Production*, *112*, 473–482.

Tang, W., Lo, Y. & Nadeem, A. (2008). Mechanical and drying shrinkage properties of structural-graded polystyrene aggregate concrete. *Cement* & *Concrete Composites*, *30*, 403–409.

Wang, Y., Wu, H. & Li, V. C. (2000). Concrete reinforcement with recycled fibers. *Journal of Materials in Civil Engineering*, *12*, 314–319.

PN-88/B-06250. Beton zwykły [Concrete].

PN-EN 206:2014-04. Beton. Wymagania właściwości, produkcja i zgodność [Concrete. Specification, performance, production and conformity].

PN-EN 12390-1:2013-03. Badania betonu. Część 1: Kształt, wymiary i inne wymagania dotyczące próbek do badań i form [Testing hardened concrete. Part 1: Shape, dimensions and other requirements for specimens and moulds].

PN-EN 12390-2:2011. Badania betonu. Część 2: Wykonywanie i pielęgnacja próbek do badań wytrzymałościowych [Testing hardened concrete. Part 2: Making and curing specimens for strength tests].

PN-EN 14889-2:2007. Włókna do betonu. Część 2: Włókna polimerowe. Definicje, wymagania i zgodność [Fibres for concrete. Part 2: Polymer fibres. Definitions, specifications and conformity].

WPŁYW DŁUGOŚCI WŁÓKIEN POLIPROPYLENOWYCH NA WYBRANE WŁAŚCIWOŚCI BETONU

STRESZCZENIE

Beton, stanowiący jeden z najważniejszych materiałów konstrukcyjny, pomimo wielu zalet (łatwość stosowania, duża wytrzymałość na ściskanie, mały koszt produkcji, odporność na działanie wysokiej temperatury) posiada też wady, do których zaliczamy przede wszystkim niską wytrzymałość na rozciąganie oraz wrażliwość na niszczące działanie czynników chemicznych. Ciągły wzrost oczekiwań odnośnie podniesienia jakości betonu sprawił, że zaczęto go modyfikować polimerami, które miałby wyeliminować wyżej wymienione wady. Zakres badań obejmował zaprojektowanie i wykonanie mieszanek betonowych modyfikowanych włóknami polipropylenowymi o długości 6, 12, i 19 mm. Do badań użyto: cement portlandzki CEM I 42,5R, piasek, kruszywo żwirowe frakcji 2–8 i 8–16 mm, wodę, plastyfikator Master Pozzolith STD oraz różnej długości włókna polipropylenowe. Wykonano trzy serie betonów zmodyfikowanych włóknami, dla których wyznaczono: wytrzymałość na ściskanie po 7, 28 i 56 dniach dojrzewania oraz nasiąkliwość, gęstość objętościową i mrozoodporność po 100 cyklach zamrażania i rozmrażania. Wykonano również badanie wytrzymałości na rozciąganie przy zginaniu po 28 dniach dojrzewania betonów poszczególnych serii.

Słowa kluczowe: włókna polipropylenowe, beton, wytrzymałość na ściskanie