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ELECTRONIC PEER-REVIEWED JOURNAL ON ALL TOPICS
OF INDUSTRIAL AND MUNICIPAL ECOLOGY

RECENZOVANÝ ČASOPIS PRO VÝSLEDKY VÝZKUMU A VÝVOJE
Z OBLASTI PRŮMYSLOVÉ A KOMUNÁLNÍ EKOLOGIE

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OBSAH / INDEX

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The deadline of the next issue is on October 8, 2020, more on January 8, 2021.

Tenebrio molitor as substrate for anaerobic digestion

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Summary

The range of organic substrates suitable for anaerobic production of biogas and bio-fertilizer is limited. The use of insect biomass for this purpose can be a feasible future solution, as this biomass is characterized by high mass gains and high lipids and protein content. The insects can be bred while being fed by difficult to degrade waste biomass or by common food biowaste. Hibernation in hypothermia allows humane way of killing insects before processing. Nowadays, the mealworm beetle (Tenebrio molitor) is being bred for the production of food. Its use for energy production should also be considered. To verify the energy balance of insect breeding and following production of biogas from its biomass it is necessary to have knowledge about production of biogas and methane. This paper discusses the results of the biochemical methane potential test of the biomass of the Tenebrio molitor larvae.

Keywords: *insect, Tenebrio molitor larvae, anaerobic digestion, biochemical methane potential test*

Introduction

As the world population is growing, there is also rising demand for energy and fuel. Global energy demand is estimated to increase up to 820 Quadrillion Btu (Q Btu)[1] by the year 2040. Traditional fossil fuels are increasingly linked to global climate change, and therefore we can see the worldwide effort to gradually reduce their use and find alternative sources of energy. The support of renewable sources of energy, such as biodiesel and biogas, is, however, globally popularized and financially subsidized.

As an alternative to fossil fuels, biogas has been receiving a lot of attention in recent years, which results in a rapid increase in its production worldwide. Between 2005 and 2016 worldwide biogas production increased almost threefold and reached approximately 61 billion m[2]. Europe is still the world leader in biogas production with more than a half of the world production of biogas. The second largest world producer of biogas is Asia with a 30 % share, followed by America with 14 %[2,3]. Nowadays, there are more than 13,800 biogas plants in Europe and the number continues to grow. Even Bulgaria and Serbia started their first installations in 2012 and joined the club of 31 European biogas countries. Unlike the previous years, there is a boom in the industry of biogas production in France, the United Kingdom, Slovakia, and especially in Italy, where in 2012 the number of biogas plants doubled from 521 to 1264 (cit[4]). Biogas production has been growing significantly also in the Czech Republic. In terms of the number of biogas plants, the Czech Republic has taken the fifth place behind Germany, Italy, Switzerland and Francei[5]. However, it is quite complicated and partly misleading to compile such ranking, as it involves only the number of biogas plants in the country and does not take into account the population or the area of the country. It would be more suitable to compare the number of biogas plants per 1 million inhabitants. The differences are smaller in this comparison. In Germany there are 130 stations per 1 million inhabitants, in the Czech Republic approximately 50[5].

Biogas can be produced from wide range of raw materials or organic waste. It mostly consists of 50 – -65% methane and 35-50 % carbon dioxide. There are also a lot of minor components[6]. Biogas can be burnt in boilers to produce heat or it can be used in gas engines to combine production of heat and electricity. After removing CO_2 and other impurities, enhanced biogas, namely biomethane or bioCNG, has almost the same chemical qualities as natural gas. It can be brought to the existing gas network or filled as a fuel into vehicles at service stations[7].

In order to maximize the benefits of biogas production, it is necessary to consider carefully which raw materials we should process. For instance, in Germany there are large fields which are only used for growing plants for energy purpose, and traditional crops for food production have to fight for space[8].

Using edible crops for production of biodiesel or biogas is not sustainable in long-term view[9]. This is also in agreement with the European Union, which legislatively supports and favours advanced biofuels[10]. The expression advanced biofuel is used for fuels which are produced without using food or feed crops, only from organic waste, for instance waste from households, kitchens, canteens, used animal fats, sludge from sewage treatment plants, dung, sawdust etc. The increasing lack of raw materials from primary production in agriculture (slurry, manure) is gradually limiting the further development of biogas production. As already mentioned, for biogas production it is necessary to process especially organic waste and only then intentionally grown energy biomass. It is vital to search for new sources of substrates suitable for production of advanced biofuels[11].

Targeted production of insects is rising. Insects have been raised especially for the purpose of production of proteins and fats, for direct production of food or as a feed. There will also be competition for the use in energy industry. The use of insect biomass as a possible raw material for biogas production has not been much considered so far. It can be hypothesized that by feeding insects with a certain biowaste, it should be possible to obtain an insect substrate with a higher or with more easily extracted energy value. This idea is also mentioned by e.g. Surendra et al[12]**.** Authors verified that *Black soldier fly* larvae (BSFL) can serve as a source of oil with high concentration of medium chain saturated fatty acids (67% total fatty acids) and low concentration of polyunsaturated fatty acids (13% total fatty acids), which makes it potentially an ideal substrate for producing high quality biodiesel.

So far, biogas production from insects has not been tested much. Anaerobic tests were carried out mainly on excrements produced by insect farming[13] or by-products from insect farming[14]. Another example of research is monitoring of methane produced by blackworm *Lumbriculus variegatus* acting on excess activated sludge[15]. The use of insects is more and more considered in the field of bio-refineries or simultaneous conversion of biomass into chemicals and biofuels. Interest in insect biomass is rising not only for the purpose of production of liquid biofuels, but also for chemical and pharmaceutical industry[16]. For instance, larvae of the mealworm beetle *(Tenebrio molitor)* are commonly used ingredient in skin whitening agents and for treatment of many skin disorders[17]. Nguyen et al used direct transesterification of BSFL kept on wheat bran to produce biodiesel[18]. The BSFL fat content was much higher (25 %) than in the wheat bran. The produced BSFL biodiesel was more stable against oxidation than rapeseed biodiesel.

In the published research, the larvae of the mealworm beetle were chosen especially for the reported high content of proteins (41 %) and lipids (27 %)[13]. Another reason for this choice is their easy, inexpensive and even nowadays widespread farming. Large-scale raising mealworms on so-called “insect farms” is mostly carried out in boxes, which are located on several floors above each other, which means high yield per unit of built-up area. Thailand is world-famous for its largest insect farms and it is the largest producer of insects in the world. Mealworms can be fed by relatively easily degradable biowaste, e.g. kitchen waste (including meat), food leftovers, old flour, leftovers from bakeries, old granules for dogs etc. Here we can see the opportunity to process poorly utilizable residues of corn, wheat, rice etc. These parts of plants represent more than a half of the world production of phytomass. If they are not ploughed in or burnt, they become waste which emits greenhouse gases without uncontrolled[16]. The impact of the production of *Tenebrio molitor* and *Zophobas molitor* for the protein source of human diet is addressed in the OOnincx[19] study. In the study, both darkling species were fed a mixture of fresh carrots, wheat bran, oats, soybeans, rye and corn supplemented with brewer's yeast. The feed conversion ratio (kg / kg fresh weight) for mealworms is reported as 2.2 in this study, which is a similar value reported for chicken farming (2.3), but at a significantly lower value than for pig breeding (4.0) or cattle (2.7 – 8.8). The energy consumption per kilogram of protein from the tested insects is about 170 MJ, which is a slightly higher value than in the case of chickens (about 150 MJ), but also lower than from pigs (about 240 MJ) or beef (270 MJ)[20]. If we compare for example bovine protein with protein from worms or crickets, insect need 12x less feed, 15x less soil, 2000x less water and produce 100x less greenhouse gases to produce the same amount of animal protein[44].

The aim of this paper was to verify practical yields of biogas and methane from the biomass of the mealworm beetle in order to obtain initial information about potential usability of this substrate in a biogas plant.

Experimental

Substrate

Dry larvae of *Tenebrio molitor* mealworm were sourced from local pet shop (see Figure 1). The larvae had a dry matter content of 95.16 %. In the biochemical methane potential test, the substrate was used in the milled state. For the test the larvae were pre-treated only by milling to the particle size ≤ 0.5 mm on IKA Tube Mill Control laboratory mill. No sieving was used. For analysis the larvae were dried to constant weight (105 °C) and then milled. The basic physical and chemical parameters are given in table 1 (see Table 1).

Figure 1: Dry Tenebrio molitor larvae in original and milled state

Inoculum

Liquid fermenting suspension (digestate) from the 1st stage anaerobic fermenter of the agricultural biogas plant Pustějov II (Zemspol Studénka, a.s.; Moravian-Silesian Region, Czech Republic) was used as inoculum. This inoculum was used to simulate the conditions in agricultural biogas plant. The values of pH, C: N ratio and other parameters (see Table 1) fit in common range[21,22].

Biochemical methane potential test (BMP test)

Discontinuous test of biochemical methane potential was performed according to the VDI 4630 standard (cit[23]). The apparatus consisted of the 1-liter reaction bottle, 1.2-liter gas burette and 2-liter expansion bottle for a closing saturated water-salt solution. The test was carried out on 500 g of inoculum. The substrate initial dose was 1.0, 4.0 and 8.0 g resulting in initial organic load marked as OL1, OL2 and OL3 respectively. For each loading two reactors were used. Also, two reactors were used for the endogenous biogas production from inoculum. Reaction bottles were placed in thermostatic water bath. The temperature of the bath was set to 40 ± 0.2 °C. Gas burettes were situated in the laboratory fume hood at 20 ± 2 °C. For the next 40 days (every working day at 7.30 am) the ambient temperature (temperature of biogas), barometric pressure and increase of biogas volume were measured. Biogas volume was recalculated to standard conditions (0 °C; 101 325 Pa). If sufficient quantity of biogas (more than 150 ml) was collected in the gas burette, analysis of biogas composition was performed using portable analyzer (GEOTECH Biogas5000, UK). During the weekend there was no measurement so the missing data on biogas volume and composition were interpolated linearly.

Table 1: Substrate and inoculum parameters

Analysis	**Parameter**			***Tenebrio molitor***	**Inoculum**	**Standard use**
Technical	pH-H_2O	pH	-	6.46	7.57	EN 15933 (cit[24])
	total solids (105 °C)	TS	%	95.16	7.27	EN 15934 (cit[25])
	volatile solids (550 °C)	VS_{TS}	$\%_{TS}$	95.81	75.82	EN 15935 (cit[26])
	density	ρ	kg/m_{TS}^3	1186	1044	EN ISO 18753 (cit[27])
Elemental (in TS)	carbon	C	$\%_{TS}$	58.06	42.37	EN 15104 (cit[28])
	hydrogen	H		8.23	4.34	
	nitrogen	N		8.94	3.64	
	oxygen	O		20.47	27.89	
	sulfur	S		0.41	0.42	EN 15289 (cit[29])
		C: N	-	6.50	11.64	
Proximate (in TS)	total combustibles	Ċ	$\%_{TS}$	96.11	68.27	ASTM D7582-15 (cit[30])
	volatile combustibles	V		82.80	55.95	
	fixed carbon	FC		13.30	12.32	
	ash	A		4.01	31.71	
Material	nitrogen compounds	NC	$\%_{TS}$	53.07	-	ČSN 46 7092-4 (cit[31])
	proteins	Prot		41.00		ČSN 467092-27 (cit[32])
	total fibers	CF		4.96		ČSN EN ISO 6865 (cit[33])
	cellulose	Cel		5.03		ČSN EN ISO 13906 (cit[34])
	lignin	CL		0.70		
	N-free extract	N-free		7.53		ČSN 467092-24 (cit[35])
	starch	Starch		7.02		ČSN 467092-21 (cit[36])
	carbohydrates (mono, oligo)	HC		0.36		ČSN 467092-22 (cit[37])
	lipids	Lip		26.90		ČSN 467092-7 (cit[38])

Results and discussion

In the BMP test the gas production from parallel reactors with the same material did not differ significantly, therefore, in graphs on the Figure 4 and Figure 5, each batch is shown with only one curve. In the reactors with the highest load, the maximal measured content of hydrogen in biogas on the second and the third day was 60 ppm, which is a value only approximately 40 % higher than in inoculum reactors (OL0) and it should not mean significant methanogen overload during acidification (reported common limit is 100-200 ppm H_2)[39]. The developments of contents of hydrogen and hydrogen sulfide in biogas from inoculum and at three different loads of substrate are shown in Figure 2 and Figure 3. It is evident that the H_2S content on the second day of the test at the highest load reached almost 1300 ppm, which might have caused temporary inhibition of methanogenesis the limit is considered to be approximately 400-500 ppm)[40], but the effect was apparently minimal, because on the fifth day of the test the content of methane was similar at all three loads (approximately 55 % vol.).

The development of daily production of biogas and methane from pure inoculum was very gradual, without an initial peak. The kinetics of the process was corresponding with the decomposition of the inoculum samples from the source given, previously tested in the workplace. Figure 4 shows cumulative developments of biogas productions. Figure 5 shows cumulative developments of methane productions. The developments of biogas and methane from the reactors with substrate additions were also without any unforeseen peaks.

In Table 2, the measured 40-day biogas and methane production are recalculated with respect to the kilogram of total solids. In the case of OL1-OL3 loading, the specific substrate productions are given, ie already after deducting the production of gas from the inoculum. The highest specific biogas production was measured, as expected, at the lowest substrate load, and it was 0.687 $Nm^3\ kg_{TS}^{-1}$. At the time, the specific production of methane was also maximal (0.442 $Nm^3\ kg_{TS}^{-1}$). As expected, both biogas production and methane production decreased with increasing load. The specific biogas production from the inoculum was almost 3 times lower than from the mixture with the highest load.

In Table 2, the practically achieved specific productions are also compared with the theoretical productions based on total solids elemental composition and calculated according to the Richards formula. The theoretical biogas production from *Tenebrio molitor was* 1.095 $Nm^3\ kg_{TS}^{-1}$ which is a very high value comparable, for example, with biogas production from corn oil (1.106 $Nm^3\ kg_{TS}^{-1}$)[41]. The practical yield of biogas from the inoculum solids was very low (22.9 %), which can be explained by the fact that it was a material in the ongoing decomposition. The practical yield of biogas from *Tenebrio molitor* solids was 62.8 % at the lowest load and decreased to 47.4 % at the highest load. A similar decrease occurred in the case of methane yield. The test results confirm the assumption and the results of the substance analysis, that the substrate contained only a minimal part of poorly degradable matter. If we add up the content of nitrogen substances, rough fibre, nitrogen-free extract, starch, simple carbohydrates and fats, the total makes almost 100 % of dry matter.

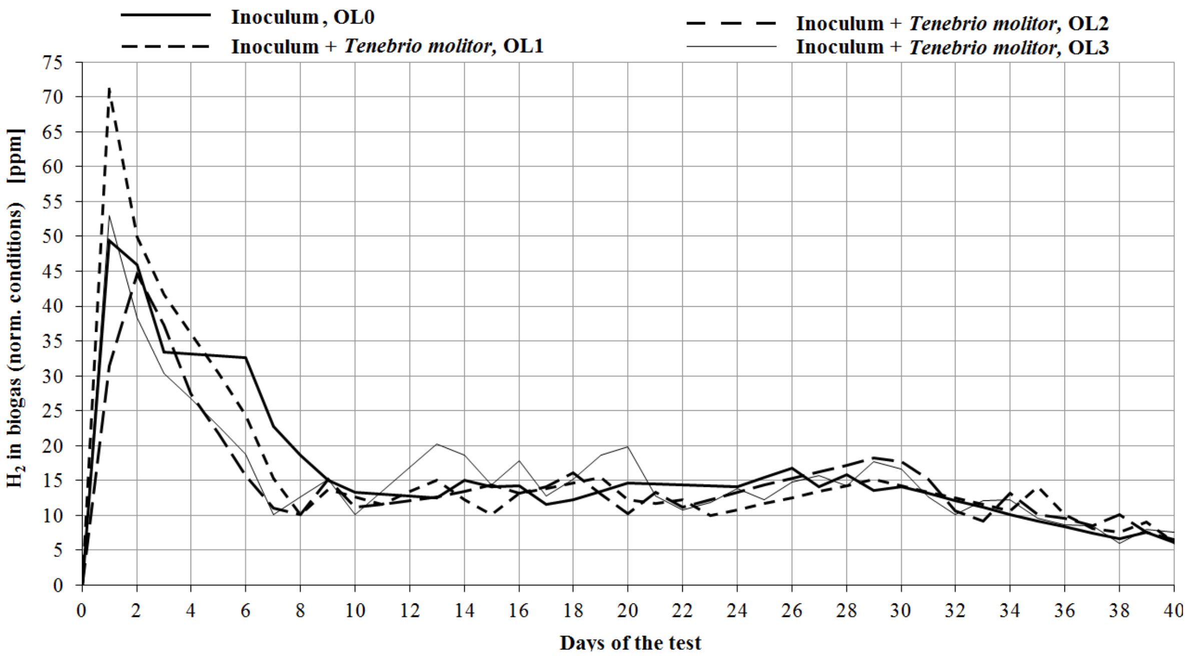

Figure 2: H_2 content in biogas

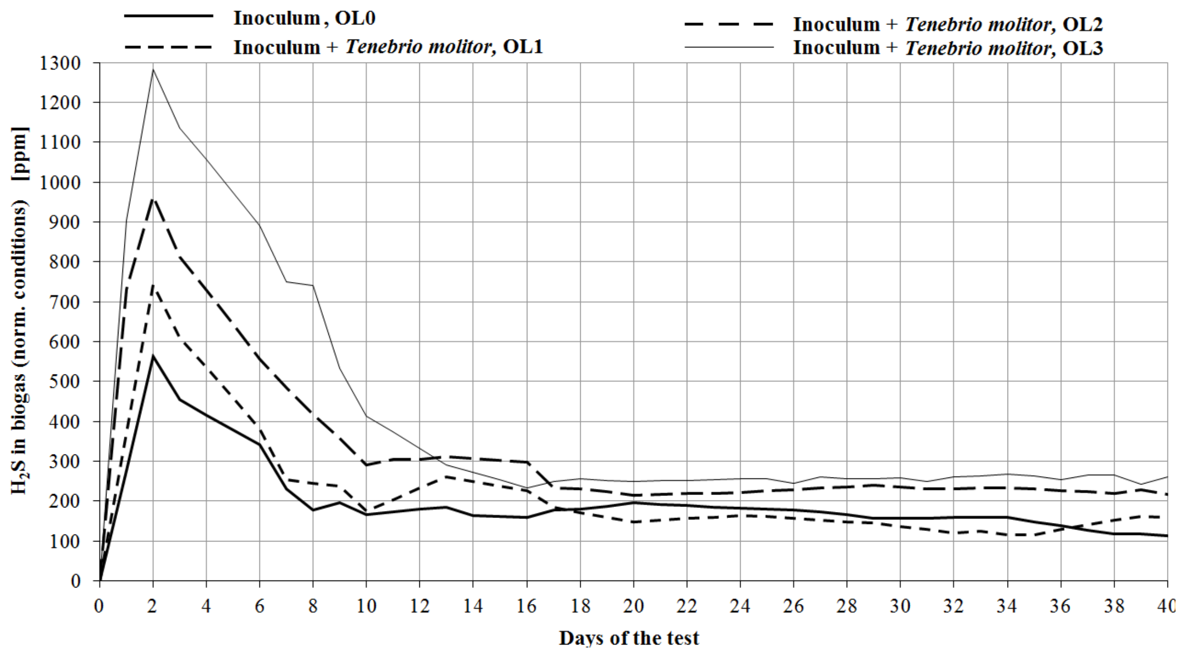

Figure 3: H_2S content in biogas

The content of CH_4 even at the highest load, exceeded the value 64 vol. % during the first week. What is specific about the substrate is fairly high content of nitrogen, approximately 9 %TS. Although neither ammoniacal nitrogen nor free ammonia was determined, in this BMP test it did not appear to have significant inhibitory effect. In practice, with higher part of substrate in co-fermentation phase, there is a risk of decreasing production of methane, but with this substrate it is not supposed to use it in a more significant proportion in the mixture. Ammonia inhibition can be suppressed by addition of substances with sorption properties, such as zeolites or biochar[39,40].

If we take into account the results at OL1 load, the dry matter of *Tenebrio molitor* larvae qualitatively corresponds, for example, to the dry matter from waste from coffee production (95.1 wt. %)[42], waste from instant soup production (93.8 wt. %)[42] or mixed waste wafer material (90.7 wt. %)[43]. The results show that from the point of view of anaerobic degradability, *Tenebrio molitor* larvae can be considered as a quality substrate. If an effective method of breeding on suitable biowaste is found, it will be possible to count on the use of larvae for biogas production.

Table 2: Theoretical and practical biogas and CH_4 production from Tenebrio molitor larvae

Initial organic load			**Biogas production**			**CH_4 content**		**Methane production**		
Total		Substrate	Theory	Test	Yield	Theory	Test	Theory	Test	Yield
OL_t		OL_s	$B_{t,V}$	B_V	η_B	% CH_4		$M_{t,m}$	M_V	η_M
kg_{VS} m^3			m_N^3 kg_{TS}^{-1}	m_N^3 kg_{TS}^{-1}	%	vol %		m_N^3 kg_{TS}^{-1}	m_N^3 kg_{TS}^{-1}	%
OL0	37	-	0.799	0.183 ± 0.009	22.9	50.1	57.8	0.400	0.106 ± 0.010	26.5
OL1	39	1.90	1.095	0.687 ± 0.055	62.8	59.5	64.3	0.652	0.442 ± 0.040	67.8
OL2	42	7.61		0.563 ± 0.039	51.4		66.1		0.372 ± 0.030	57.1
OL3	47	15.23		0.519 ± 0.031	47.4		64.3		0.334 ± 0.023	51.2

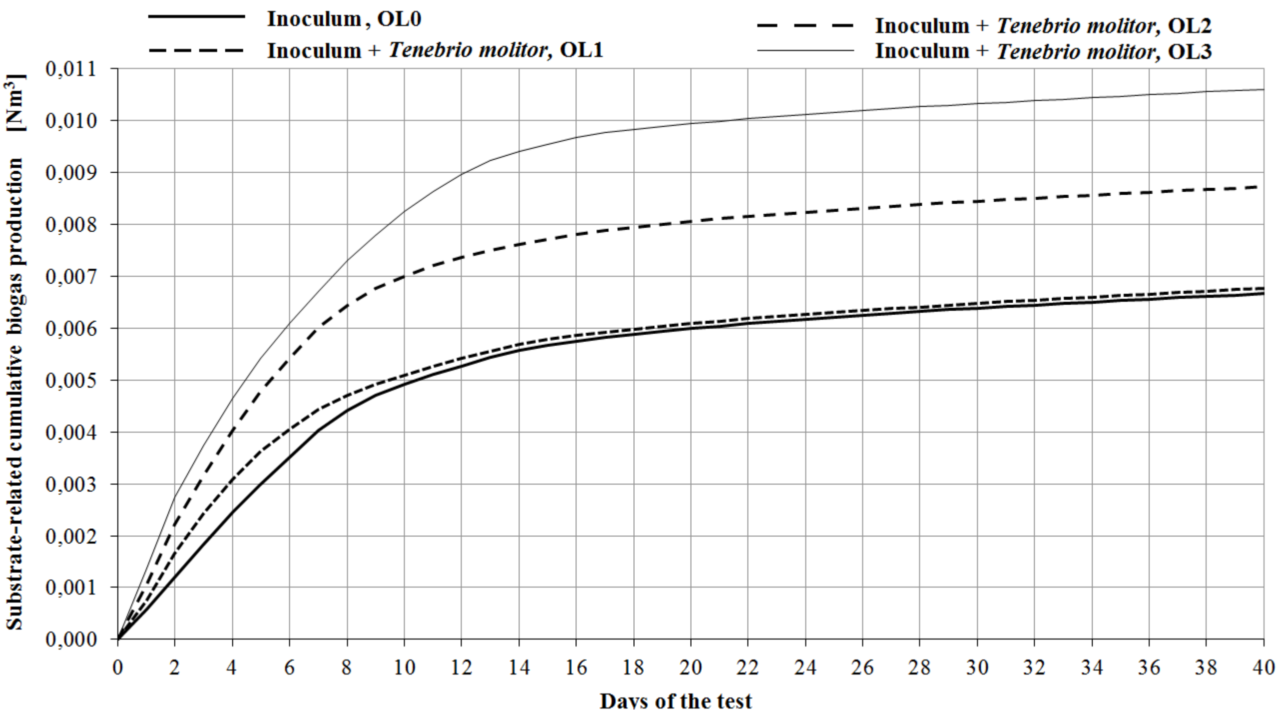

Figure 4: Cumulative biogas production from reactor with inoculum and with substrate additions

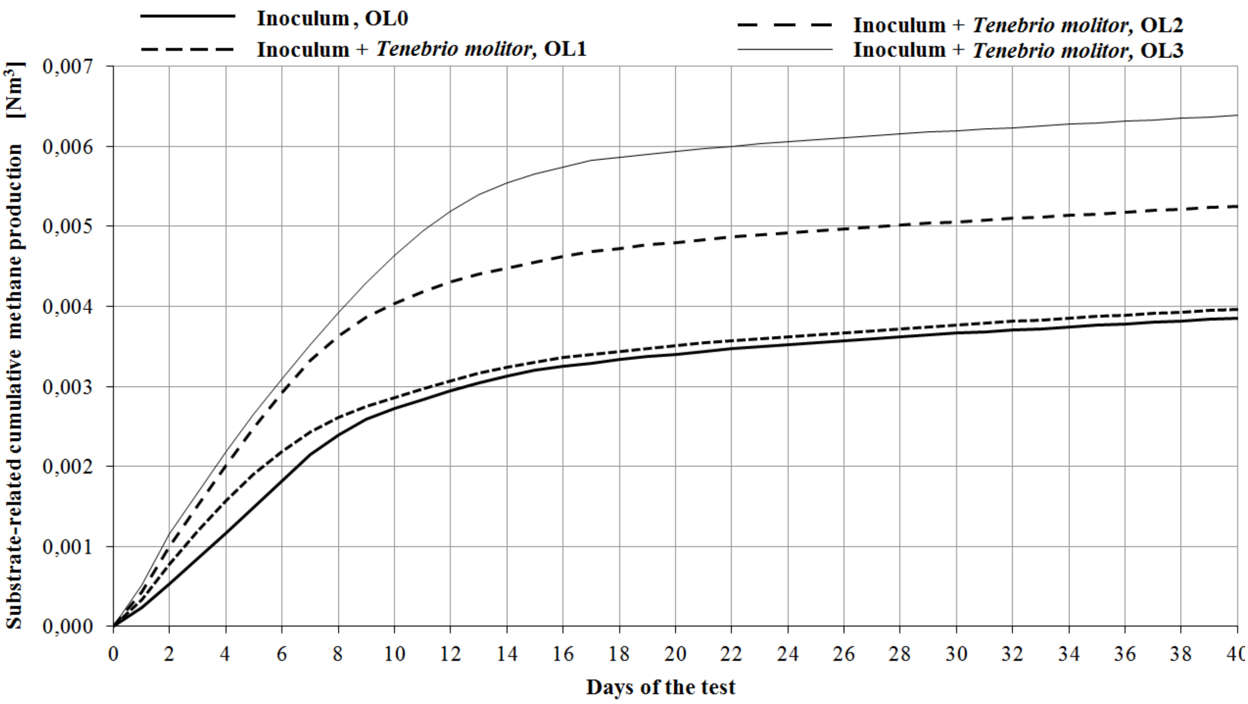

Figure 5: Cumulative CH_4 production from reactor with inoculum and with substrate additions

Conclusions

Very high biogas and methane production from larvae of the *Tenebrio molitor* were verified in the forty-day test of batch anaerobic digestion. The material can be considered a substrate of very good quality, containing over 40 % proteins and almost 30 % lipids. However, if it should be used in a larger addition, it is necessary to take into account very high content of nitrogen and the inhibition problems connected. By mixing the substrate with conventional biomass, such as maize silage, organic waste from maintenance of urban green areas, a separated organic fraction of municipal solid waste etc., the parameters of the process can possibly be enhanced.

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Tenebrio molitor jako substrát pro anaerobní digesci

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Souhrn

Paleta organických substrátů vhodných pro anaerobní výrobu bioplynu a hnojiva je omezená. V budoucnu může být k tomuto účelu využívána i biomasa hmyzu vyznačující se vysokými přírůstky hmoty, vysokým obsahem tuků a bílkovin. Hmyz může být chován při krmení obtížně rozložitelnou odpadní biomasou nebo běžným potravinovým odpadem. Hibernace při podchlazení umožňuje humánní usmrcení hmyzu.

Potemník moučný (Tenebrio molitor) je již nyní chován pro produkci potravin. Rovněž jeho využití pro energetické účely by mohlo připadat v úvahu. Pro ověření energetické bilance chovu a návazné výroby bioplynu z biomasy hmyzu je nezbytné znát produkci bioplynu a methanu. V tomto příspěvku jsou diskutovány výsledky testu biochemického methanového potenciálu hmoty potemníka moučného.

Klíčová slova: *hmyz, larvy Tenebrio molitor, anaerobní digesce, BMP test*

Thermal treatment of by-product from cement-bonded particleboards production for further use

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Abstract

This paper presents the issue of thermal treatment of by-products arising in the production of cement-bonded particleboards. These by-products are formed during the processing of cement-bonded particleboards (cutting and grinding). The aim of the presented research was to evaluate the effect of thermal treatment on the properties of the mentioned by-products and then cement composites with containing these compounds. The reason for the research was to assess the possibility of activation of by-products from the production of cement-bonded particleboard with regard to participation during the formation of the structure of the cement matrix. The heat treatment of the by-products took place at temperatures of 1000 °C and 1200 °C. Thermally treated offcuts and dust (from two collection towers) were applied to cement composites as a partial cement replacement in amounts of 10 and 25%. Subsequently, the influence on physical-mechanical properties of mortars including changes in chemical, resp. mineralogical composition and microstructure was evaluated. The properties and behaviour of the materials were monitored and evaluated at the age of 28 and 90 days of curing.

***Keywords:** Cement-bonded particleboard, by-product, thermal treatment, cement mortar, microstructure, gross heat of combustion, mechanical resistance.*

Introduction

When cement-bonded particleboards (CBPB) are manufactured both lump, as a residual cuts-off after the boards formatting and powder-like by-products are formed after various processing operations such as drilling, grinding or spinning, being collected in dust extractors. In the Czech Republic within one production plant it is annually produced about 10000-12000 t of such by-products that are landfilled.

Cement-bonded particleboards are made of cement, water, natural lignocellulose (organic compound) in the form of wood chips and mineralising compounds in percentual mass ratio about 50:30:18:2 (cement, water, wood chips, admixtures). It is the considerable content of wood in the by-product that offers the possibility of use of gross heat of combustion in combustion processes in industry and energy, while the variability of raw materials, their chemical and mineralogical composition affects the decomposition and eventually sintering of emerging by-product which can be associated with clogging of the combustion systems depending on combustion technology. The use of combustion heat can help reduce the cost of primary raw materials and landfilling of by-products, in addition, combustion processes produce additional by-products occupying only a fraction of the volume of original combustible compounds and has the potential for use in building materials technology due to latent hydraulic or pozzolanic properties[1-4]. As a 15% partial replacement for cement G.B. Ramesh Kumar and V. Kesavan[5] used coconut fibre fly ash in their study, which reduced strength characteristics of concrete. S. Loganayagan et al.[6] used ashes from cane bagasse in the range of 5-15% by weight of cement, with a more pronounced decrease in 7-day strengths, but 28-day compressive strength did not show significant decrease. L. Hu et al.[7] used ashes from cane bagasse in the range of 5 – 15% by weight of cement, with a more pronounced decrease in 7-day compressive strength, but 28-day compressive strength did not show significantly lower performance.

With regard to the findings of authors dealing with relevant issues, the subject of this study is the evaluation of the possibility of using thermally treated by-products from the processing of cement-bonded particleboards.

Experimental part

Offcuts created during the formatting of the boards, fragments, or scrap pieces (C) of cement-bonded particleboards were supplied by the domestic board manufacturer. In terms of the composition of the offcuts, it is a composite material containing cement matrix with wood chips that have been mineralized with water glass. Dust from production, which forms mainly during the cutting, milling, grinding and drilling of CBPB or during the extraction of dusty spots on the production line, captured in 2 dedusting towers (marked T2 and T4) was supplied by the manufacturer. In tower 2, there is a by-product extracted from the formatting saw, where the dust is extracted via a cyclone. This type of by-product represents the highest volume and contains the largest grains. In tower 4, there is a by-product extracted from the milling machine and a CNC machine.

Selected properties of the raw materials are listed in Table 1 and the particle size is shown below in Figure 1. Density of raw materials was measured with AccuPyc II 1340 Pycnometer which accuracy is 0.03 %. The results of the particle size distribution were obtained with laser analyser Malvern Mastersizer 2000 and indicate that by-product T4 is finer, which is noticeable especially in the area of 0 - 100 μm containing about 20 % more grains than the T2. However, there is no distribution curve for the offcuts due to the variability of their sizes which can be up to 80×300×10 – 16 mm as their thickness varies (which corresponds to the current production of CBPB).

Table 1: Properties of raw by-products

Material	C	T2	T4
Properties			
Density [kg/m^3]	2350	2230	2270
Loss on ignition [%]	40.2	35.2	42.7
Gross heat of combustion [J/g]	4117	3613	2843

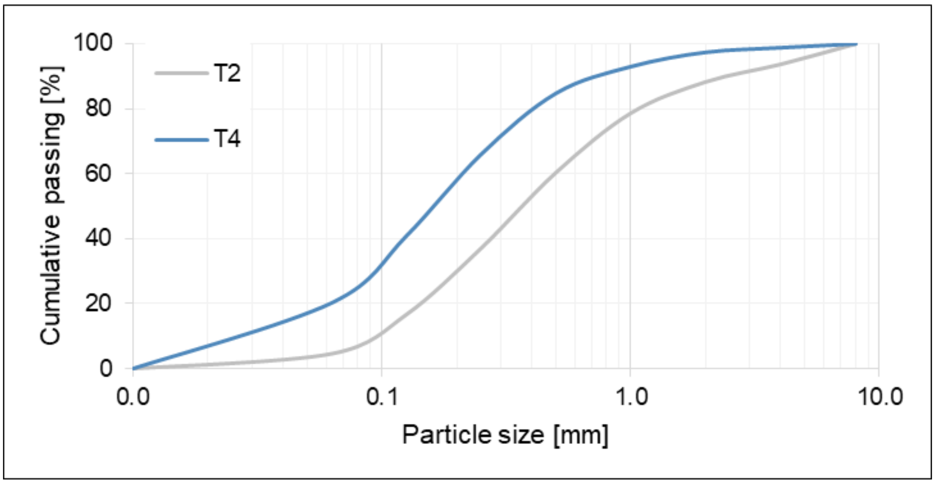

Figure 1: Cumulative particle size distribution of untreated by-products

Before the thermal treatment the offcuts from the formatting saw were crushed for further use in a jaw crusher with a maximum jaw opening of 2 mm according to the settings tested by Melichar et al. in previous research[8]. The dust from collection towers and the crushed offcuts were further subjected to thermal treatment at 1000 resp. 1200 °C in a kanthal electric laboratory furnace CLASIC 2018S with a temperature rise 10 °C/min at isothermal endurance 60 min. To determine the impact of thermal treatment of the raw materials, the loss on ignition was carried out on samples weighing 10-15 g with accuracy 0.01 g in a platinum vessels placed in the laboratory furnace and treated at 1000 °C for 60 min. The potential for heat utilization from wood was determined according to EN ISO 1716[9] as the gross heat of combustion (GHC) using the calorimeter IKA C200 with temperature measurement resolution 0.0001 K. The specific surface area was determined using the Blain permeable method (ZEB MAXAM PC-Blaine Star). Phase composition was studied using X-ray diffractometer Empyrean Panalytical (CuKα radiation) with angular resolution 0.026 °. The properties of the thermally treated materials (TTMs) are given in following Table 2 and the particle size is stated in Figure 2 below. Crystalline phases are identified in Figure 3.

Table 2: Properties of thermally treated materials

Material	C 1000	C 1200	T2 1000	T2 1200	T4 1000	T4 1200
Properties						
Density [kg/m^3]	3170	3160	3150	3160	3140	3170
Specific surface area [m^2/kg]	477	278	416	222	491	244
Mineral composition (XRD)	Lime, C_2S, C_3S, C_4AF, C_3A, Calcite, Portlandite, Anhydrite					

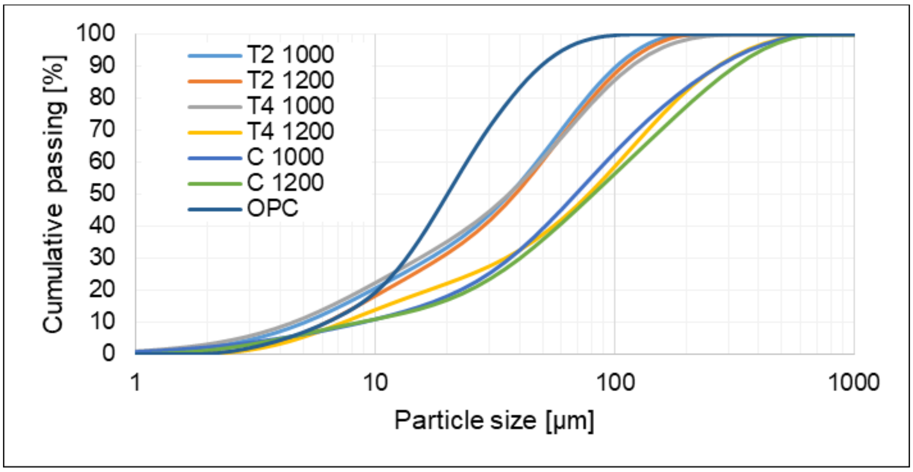

Figure 2: Cumulative particle size distribution of treated by-products and ordinary portland cement

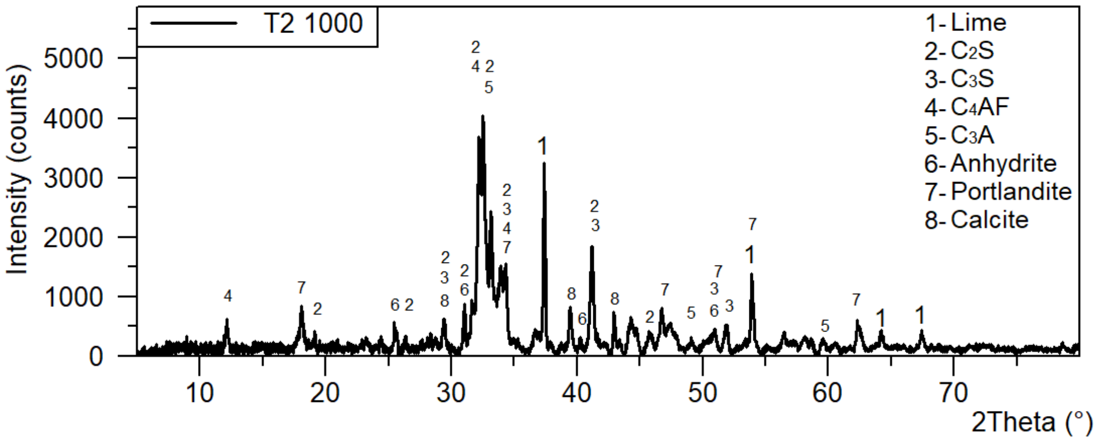

Figure 3: XRD pattern - crystalline phase identification of thermally treated material (T2)

The resulting TTMs were applied into the mortars for production of the test specimens. A total of 6 test specimens with dimensions of 40×40×160 mm were prepared according to EN 196-1 from each batch with the mixture proportioning given in Table 3 and consequently they were tested on a pressure device RT 200/10-1 D servo with accuracy class 1 according to EN 196. The error bars within the results represent a standard deviation. The impact of the 10% resp. 25% partial replacement of cement by weight with thermally treated offcuts and dust was studied.

Table 3: Mixture proportioning

Mixture	Sand	Water	OPC	TTMs	Notes
REF			900	0	Reference mixture
C 10/10			810	90	Mixture proportioning is stated in grams per batch.
C 10/25			675	225	
C 12/10			810	90	
C 12/25			675	225	
T2 10/10			810	90	Ordinary Portland Cement (OPC) was used type: CEM I 42.5 R according to EN 197-1[11].
T2 10/25	2700	450	675	225	
T2 12/10			810	90	
T2 12/25			675	225	
T4 10/10			810	90	Mixture coding (11 22/33) represents type of original by-product (11) as a partial replacement for cement, temperature of treatment in °C divided by a hundred (22) and percentage of cement replacement (33).
T4 10/25			675	225	
T4 12/10			810	90	
T4 12/25			675	225	

The properties of hardened mortars were determined by bulk density from the dimensions and weight of the test specimens, compressive strength and flexural strength according to EN 196-110, as well as the activity index according to EN 450-112 which is determined as the ratio of the compressive strength of the modified mortar to the reference one after 28 and 90 days. The dimensions were measured with a digital calliper KINEX 6040-15-200 with a resolution of 0.01 mm and the weight was obtained with a laboratory scales KERN PCB 1000-2 with readability of 0.01 g. Furthermore, the analysis of mineralogical composition was performed using X-ray diffraction on a PANalytical Empyrean diffractometer (CuKα radiation) on a dust samples passed through a sieve of mesh size 0.063 mm and comparison of the microstructure was performed on images taken with TESCAN MIRA3 XMU scanning electron microscope with resolution 1.2 nm at 30 kV, for test specimens aged 28 and 90 days in a standardized laboratory environment, as well.

Results and discussion

From the results of the values of GHC for 3 different by-products from the production of cement-bonded particleboard, it was found out that the highest yield of heat can be gained from crushed offcuts, where the value of GHC reaches 4.117 MJ/kg. The values of GHC from the captured dust from towers 2 and 4 were 3.613 MJ/kg and 2.843 MJ / kg, respectively. Compared to the values of combustion heat of other materials, such as firewood (16 MJ/kg), hard coal (21-31 MJ/kg), the values are several times lower[13]. By the combustion of rice husks, L. Hu et al. indicate GHC value of 14.3 MJ/kg[7]. The diametrical differences among the GHC values is due to the composition of the by-product, which consists of cement matrix and wood chips which are mineralised.

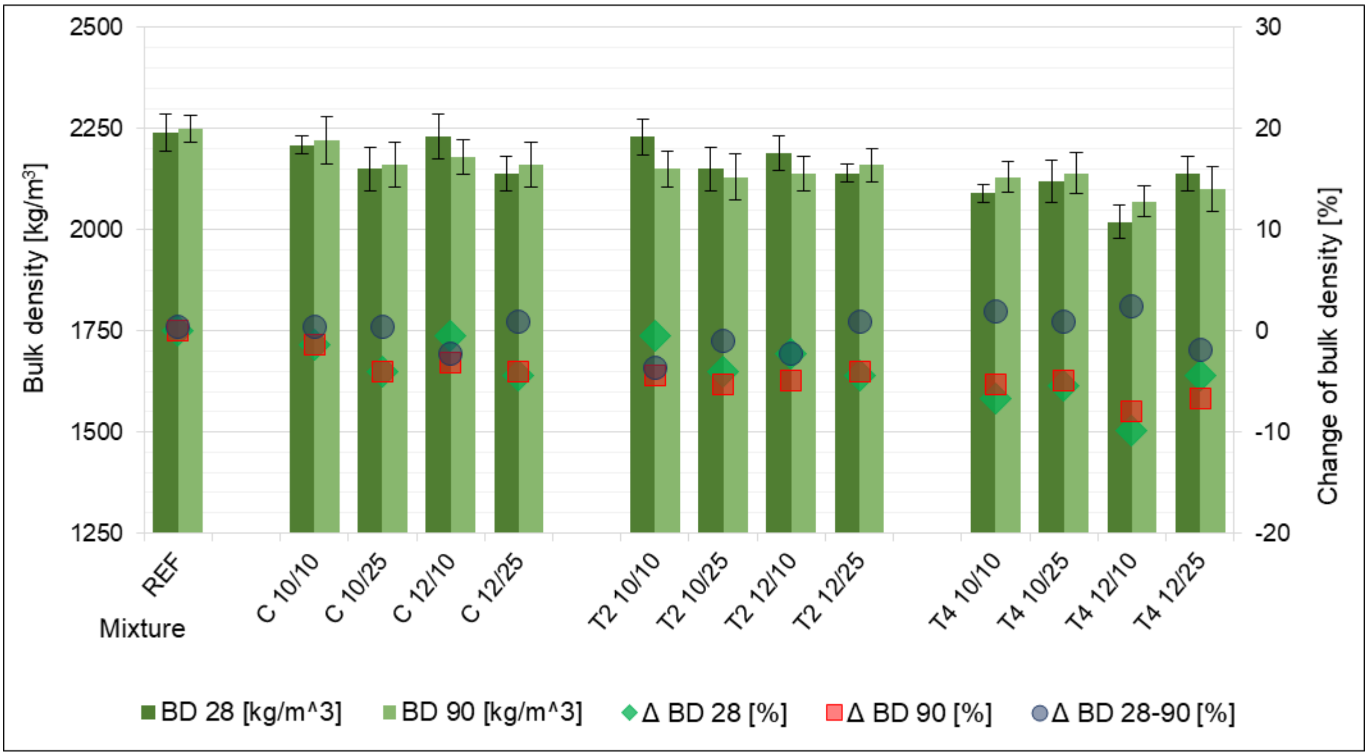

Figure 4: Comparison of bulk density (BD) of mortars

From the results of the determination of bulk density of hardened mortars after 28 and 90 days of curing (see Figure 4) it is evident that the cement replacement of 10 % and 25 % resp. with TTMs reduces the bulk density by less than 10 % on average compared to the reference mixture. The most significant decrease in bulk density is evident in the T4 12/10 and T4 12/25 series, where the 10% cement replacement caused more significant decrease than the 25% replacement. In most cases, it has been proved that the bulk density of mortars decreases with increasing cement replacement. This trend was not reflected in the T4 series, where it was the opposite. The difference in strength after 28 and 90 days fluctuated in almost all recipes around 2% upwards and downwards, thus no clear trend of the thermal treatment of individual raw materials on the bulk density of mortars over time was proved.

The results of flexural strength shown in Figure 5 indicate that 10% cement replacement does not have a significant negative impact on flexural strength, moreover in most cases there is an improvement of up to 8.1% for 28-day strengths and 10.3% for 90-day strengths. 25% cement replacement results in a slight decrease of 28-day strengths by up to 11.6%, however 90-day strengths appear to have a slight improvement over the reference mortar. The T4 series show more noticeable decrease in flexural strength, which is in line with the lower bulk density. The difference between the temperature of thermal treatment of the raw materials was reflected in the tensile strength in bending in such a way that the higher temperature resulted in an increase in strength at 10% cement replacement and a decrease in strength at 25% cement replacement. In this case, the effect of the extent of substitution was more pronounced than the impact of thermal treatment. In terms of the role of TTMs in the hydration products formation of the cement matrix, it can be concluded rather the predominant function as a filler and only marginal involvement during the hydration reactions.

The compressive strength, shown in Figure 6, with a 10% cement replacement, indicates more pronounced decrease in strength compared to the reference mortar, up to 7.3 % after 28 days and by 10.6 % after 90 days. A 25% cement substitution resulted in some mixtures in an even lower strengths of both 28-day cured specimens by up to 17.1 % and 90-day cured specimens where the compressive strength decreased by up to 19 % compared to the reference which is in accordance with the results of Rajamma et al. (2009)[1]. The lower bulk density affected the compressive strength much more than the flexural strength.

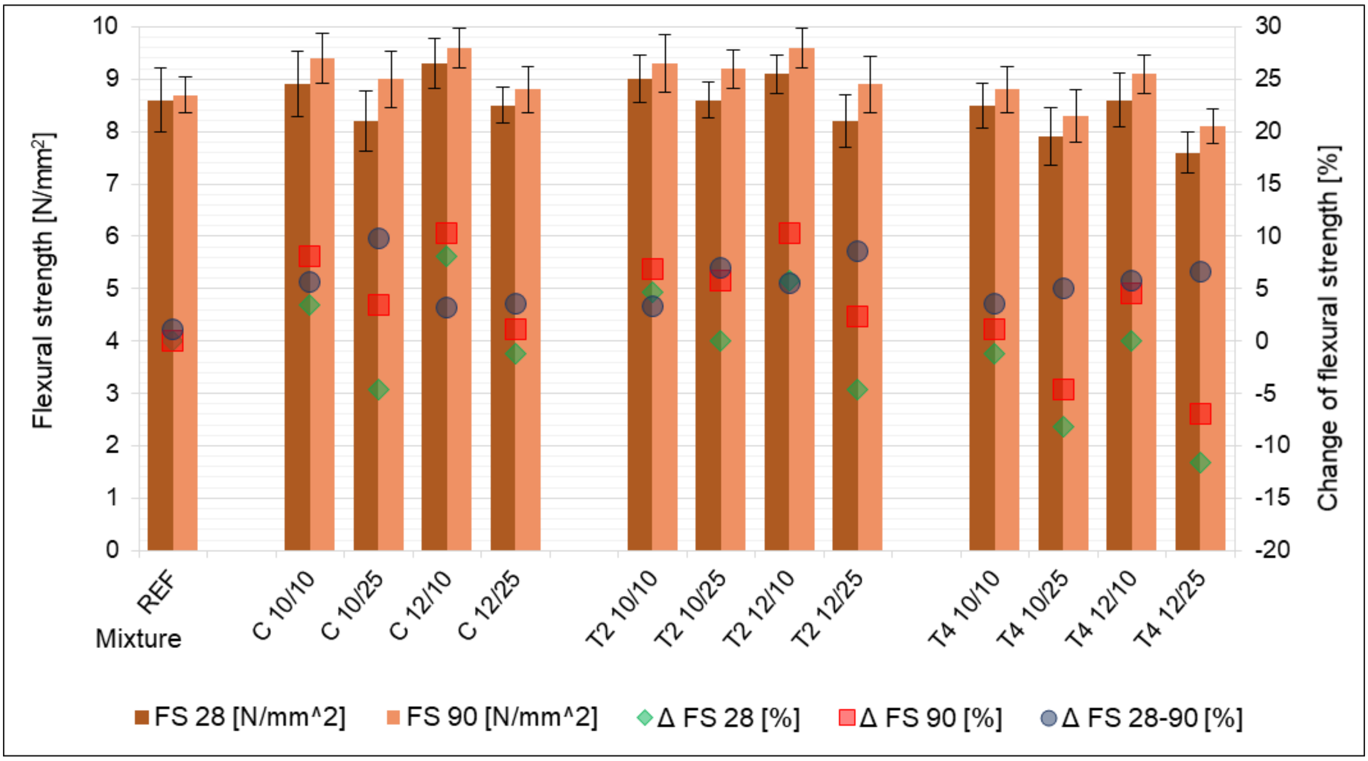

Figure 5: Comparison of flexural strength (FS) of mortars

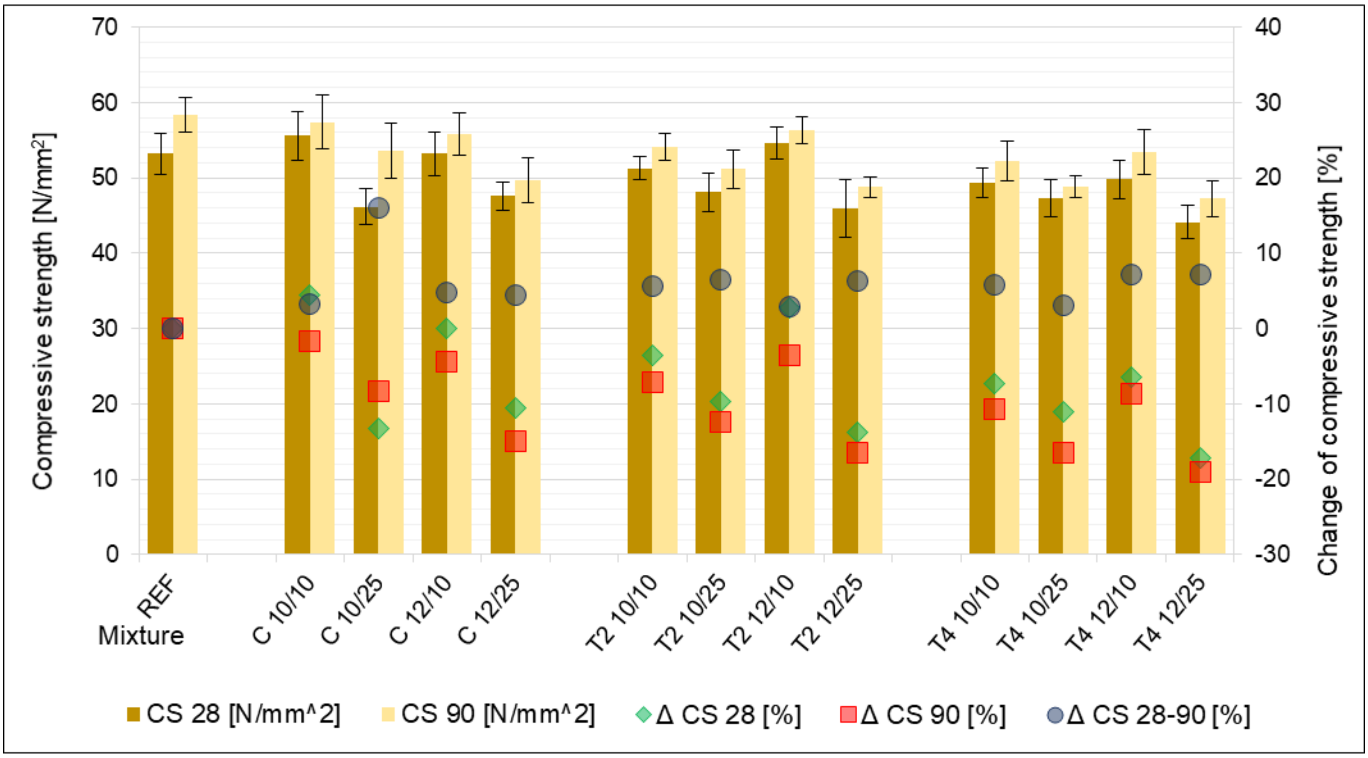

Figure 6: Comparison of compressive strength (CS) of mortars

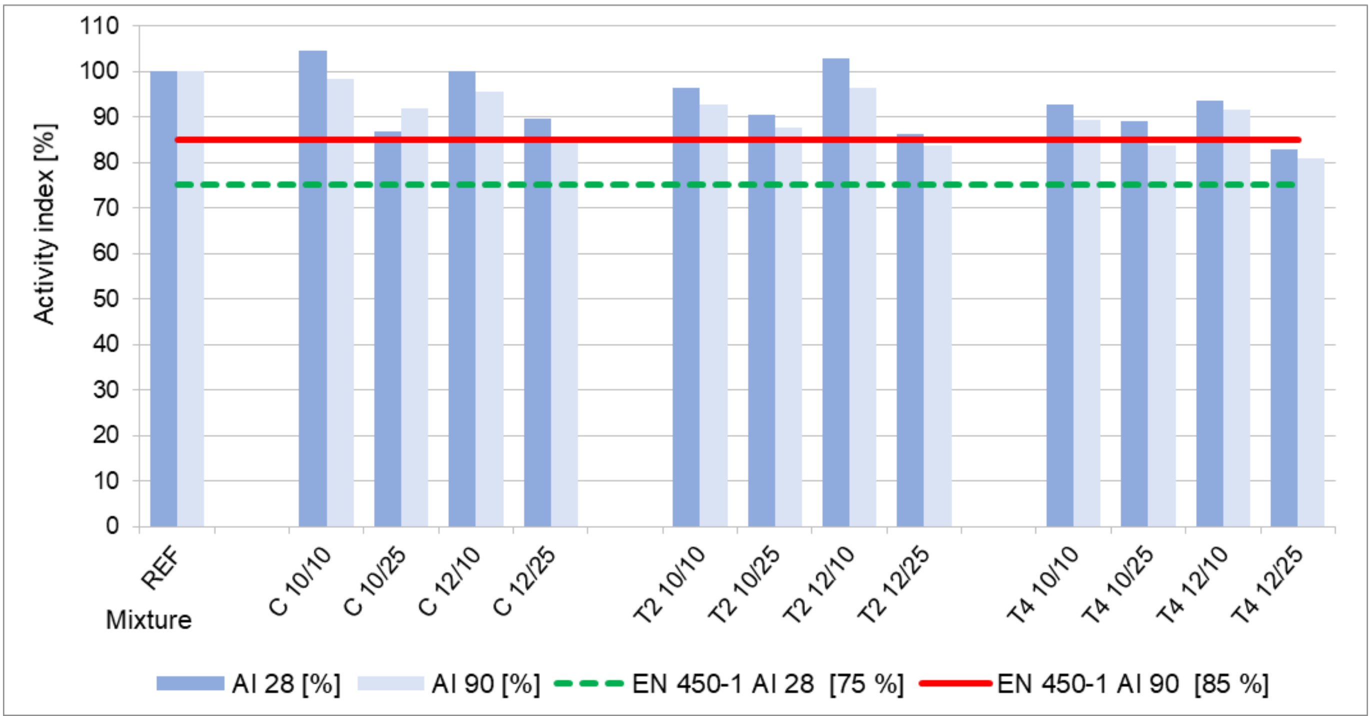

Figure 7: Comparison of the activity index (AI) of tested mortars at 28 and 90 days of curing. The 75% and 85% lines represent the minimal standard requirements.

The activity index values (see Figure 7) indicate the fact that the tested materials meet the requirements of the technical standard EN 450-1 with the exception of the case of 90-day strengths (specifically the mixture T2 12/25, T4 10/25 and T4 12/25).

Using X-ray diffraction, minerals were identified in TTMs: quick lime, C_3A, C_2S, C_3S, C_4AF, calcite, portlandite and anhydrite. Clinker minerals are found in the raw material as part of imperfectly hydrated cement, which binds the original wood-cement composite, while the quick lime, C_3A and anhydrite are formed in the TTMs due to thermal treatment as the products of decomposition of portlandite (460-550 °C), calcite (700-950 °C) and ettringite (80-380 °C)[14]. The quick lime reacts with water to form $Ca(OH)_2$, which is an exothermic reaction. Another exothermic reaction occurs when the anhydrite reacts with water to form gypsum, which causes an excessive water evaporation and also faster setting and lower strength. Lime also reacts with anhydrite in the presence of water and together with reactive C_3A forms a bulky ettringite which causes a significant volume changes, stresses, and cracking. The higher the quick lime content in TTMs is the more poor-strength portlandite forms at the expense of the content of CSH as the main binding components of the cement matrix formed during the hydration of C_3S and C_2S[15,16].

The following SEM images show the microstructure of mortars containing the offcuts (C) (see Figure 8) and T2 dust (see Figure 9). The mortars with a higher dose of the substitution component (25%), were deliberately selected in order to make more obvious the differences in the structure of the investigated materials. The analysis of the microstructure indicates minimal differences between the individual recipes, moreover no significant anomalies were found. The components found within the matrix corresponded to the findings of the X-ray diffraction analysis. Microcracks were found locally in the structure of the investigated samples, which could be related to a decrease in strength parameters confirming the theories found in literature (Tokyay, 2016[15], Barends et al., 1999[16]). Except for these defects, the microstructure appears compact with fully developed hydration products.

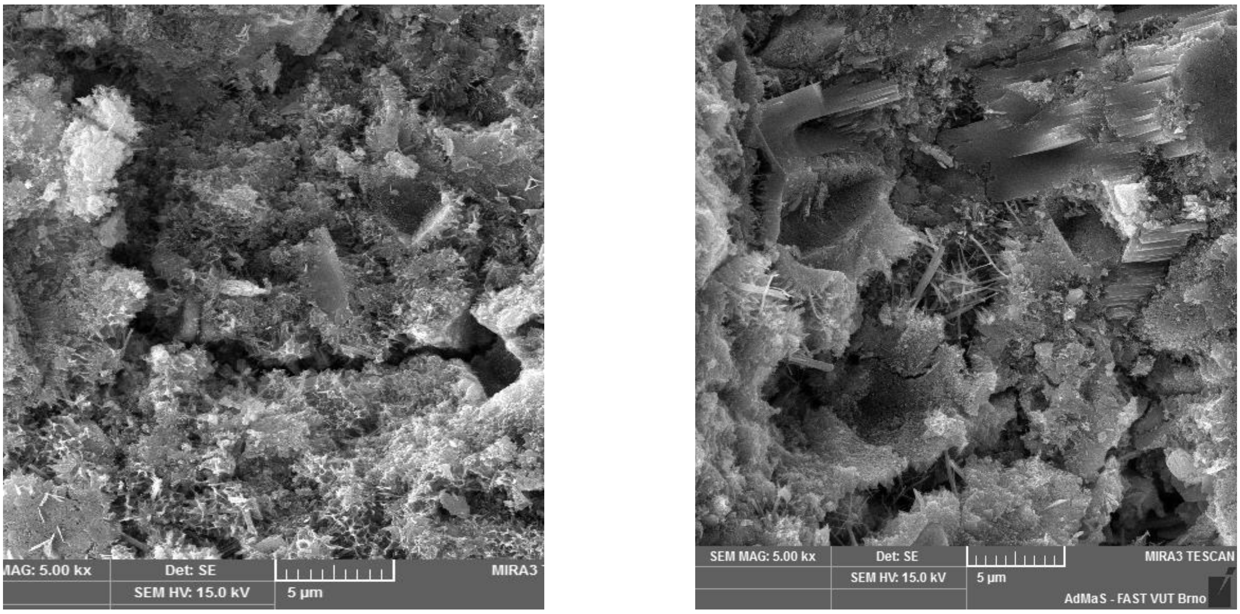

Figure 8: SEM images of mortar C 10/25 (on the left) and C 12/25 (on the right) at 5000x magnification. Cement matrix indicates plate-like calcium hydroxide crystals surrounded by amorphous C-S-H phase. Rather porous and cracked texture also contains short column-like crystals of gypsum and needle-like ettringite crystals.

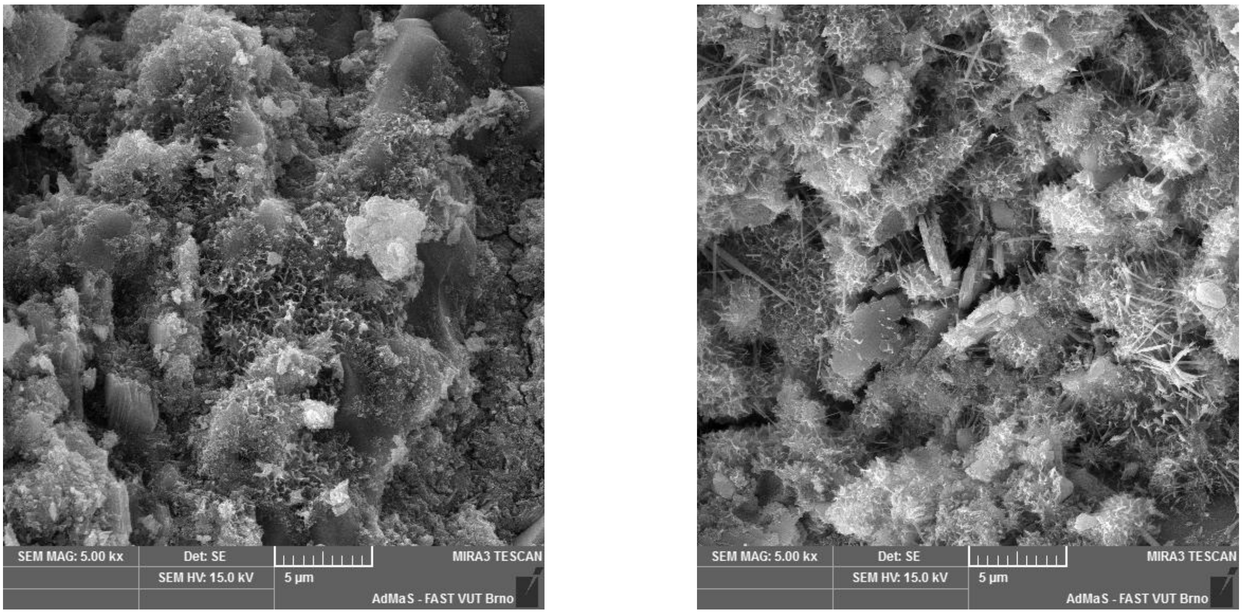

Figure 9: SEM images of mortar T2 10/25 (on the left) and T2 12/25 (on the right) at 5000x magnification. Amorphous C-S-H phase is formed on larger quartz sand grains and crystals of calcium carbonate. Needle-like ettringite is formed in the gaps.

Conclusions

The results presented in this research paper show the options of use of the thermally treated offcuts and dust, from processing of cement-bonded particleboards, in cement mortars, which is highly probable that has not been investigated so far. The usable heat from by-products after the processing of cement-bonded particleboards is in the range of 2.843-4.177 MJ/kg, which is several times lower than for the common primary solid fuels (coal, wood etc.). However, it is not a negligible value and a certain energy potential can be found.

Following the results, it is evident that the thermally treated by-products from the processing of cement-bonded particleboards can be used for the production of composite materials based on cement matrix to a limited extent, with at most 10% of the amount of cement appearing to be optimal. In the case of materials that do not require high performance (e.g. interior plaster, etc.), it would be possible to consider higher cement substitution (e.g. 25 %). These findings are also reported in a review by Cheah et al. (2011)[2].

10% and 25% cement replacement with thermally treated materials reduces the bulk density and strength of cement mortars.

The main cause of the decrease in compressive strength in mortars with cement replacement of 10 % and 25 % respectively could be, among other things, the quick lime contained in thermally-treated materials, which, due to its high reactivity, promotes the volume changes in reactions with water, anhydrite and C_3A.

CaO forms more portlandite at the expense of the CSH phases and generates excessive heat at the beginning of hydration, which results in defects in the microstructure of the cement matrix and its poorer cohesion.

By the cement replacement with TTM after processing of cement-bonded particle composites, the compressive strength of mortars above 80 % compared to the reference can be achieved. In terms of activity index, where the requirement is 75 % after 28 days, respectively 85 % after 90 days, it can be stated that only three mixtures did not comply, namely T2 12/25, T4 10/25 and T4 12/25, which is thermally treated dust replacing 25 % of cement.

Further investigation to the use of by-products from the processing of cement-bonded particleboards appears to be very interesting from the point of view of follow-up research, where attention will be focused on higher temperatures of thermal treatment (1400-1600 °C) including different cooling regimes (corresponding to real combustion processes) and further investigation of durability of cement composites modified by thermally treated by-products.

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Termická úprava vedlejšího produktu z výroby cementotřískových desek pro jeho další využití

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Souhrn

Článek prezentuje problematiku termické úpravy vedlejších produktů vznikajících při výrobě cementotřískových desek. Tyto vedlejší produkty vznikají při opracování cementotřískových desek (řezání a broušení). Záměrem prezentovaného výzkumu bylo hodnocení vlivu termické úpravy na vlastnosti zmíněných vedlejších produktů a dále pak cementových kompozitů s příměsí obsahující tyto složky. Důvodem realizovaného výzkumu bylo posouzení možnosti případné aktivace vedlejších produktů z výroby cementotřískových desek s ohledem na participaci během utváření struktury cementové matrice.

Termická úprava vedlejších produktů proběhla při teplotách 1000 °C a 1200 °C. Tepelně upravené odřezky a prach ze dvou záchytných věží byly do cementových kompozitů aplikovány jako parciální substituent pojiva v množství 10 a 25 %. Následně byl posuzován vliv na fyzikálně-mechanické vlastnosti, vč. změn chemického, resp. mineralogického složení (XRD) a mikrostruktury (SEM). Vlastnosti a chování hmot bylo monitorováno a hodnoceno ve stáří 28 a 90 dní.

Klíčová slova: *Cementotřísková deska, vedlejší produkt, termická úprava, cementová malta, mikrostruktura, spalné teplo, mechanická odolnost.*

Cut Flowers and Greenhouse-Gas Production during the Landfilling of Biodegradable Municipal Waste

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Abstract

Cut flowers create a pleasant atmosphere, influence the aesthetic feeling of the perception of many life situations. Unfortunately, faded flowers end at landfills, where they are subject to anaerobic digestion, producing significant amounts of greenhouse gases. In addition, their use also involves air and car transport and thus carbon-dioxide emissions.

The total emissions from deposited roses is 0.41 mil. m^3 methane and 28492 t CO_2, from deposited chrysanthemums 0,13 mil. m^3 methane and 9 149 t CO_2, and from carnations 0,04 mil. m^3 methane and 2 624 t CO_2.

A summary of the hidden ecological contexts associated with greenhouse gases in selected species of cut flowers is provided below.

***Keywords:** greenhouse gas, municipal waste, cut flowers*

1. Introduction

The Diderot Encyclopaedia[1] describes flowers as the ‘species and cultivars of plants grown for decorative purposes’. Nevertheless, flowers are currently also a sought-after trade item and include a great variety of species. The text below focuses on cut flowers only, which defines as ‘flowers separated in any way from the plant including the stem, sometimes with the other leaves or with lateral axes’. The actual flower may consist of one flower (rose, carnation etc.), inflorescence (gerbera) or clusters (hyacinth).

In the Czech Republic, the total production of flowers (from cultivation areas, greenhouses and covered areas) in 2016 experienced a year-on-year increase of 3.7 % in comparison with the year 2015 to 2.17 milliard CZK and the import of flowers of 15.2 % to 3.23 milliard CZK. Czech growers exported flowers in the value of 516 million CZK, with their export having increased by 14 %.

Flowers are most frequently transported from growers through flower auctions and wholesalers to customers by road and air. Road transport is used within Europe, i.e. also to the Czech republic (CR), when flowers are transported in special lorries equipped with a cooling system, which maintains the temperature of the transport space with special containers (envirotainers) with cut flowers below 5 °C. Air transport is mainly used for long-distance transport, e.g. of cut flowers from Asia, Africa or South and North America. Yet it is also utilised when it is necessary to transport cut flowers that are already mature for harvest quickly within Europe. In some cases, also ship transport employing cooling boxes is used in combination with road transport. The storage spaces of flower auctions, where the biggest business transactions take place, are equipped with the necessary cooling devices. Their operation, however, requires the consumption of electricity, whose production is associated with carbon dioxide emissions.

Last year, the highest number of flowers was imported into the CR from the Netherlands, Germany and Denmark. Conversely, domestic flower growers exported mainly to Slovakia, Germany and Poland. In 2016, each inhabitant of the CR spent on average CZK 1,091 on flowers, whereas it had been CZK 991 one year earlier.

The flowers grown in the CR include especially balcony and flower-bed flowers, primulas, chrysanthemums, cyclamens and poinsettias. In 2013, the production of flowers decreased, for the first time in nearly two decades, by 3 % to 1.88 milliard CZK. The factors significantly involved in the decrease included bad weather, long winter and the lack of sunshine in the spring. The crops of flower growers were also negatively influenced by summer floods. In the next three years, the production began to increase again – see Fig. 1 [3].

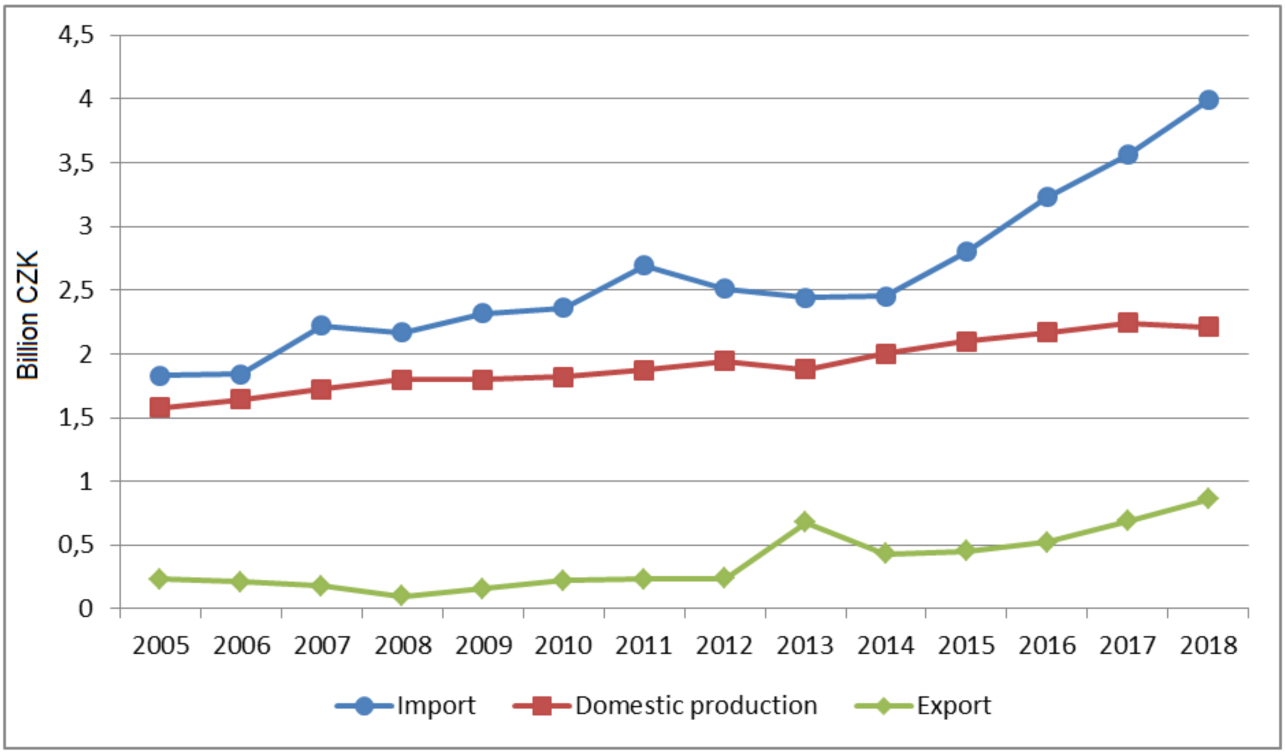

Fig.1: Flower market in the CR [In Billion CZK]

Having fulfilled their aesthetic, decorative and ceremonial functions, cut flowers mostly end at municipal solid waste landfills, where they are subject to decay, producing greenhouse gases, which are strictly monitored and specifically regulated now [4].

Greenhouse-gas emissions accelerate the global climate change, which has a profound impact on the biosphere. The following expenditures take into account negative changes in the conditions, including temperature rise (heat waves, periods of drought), climate changes and other changes related to them (the reduced occurrence of endemic species), more frequent extreme weather conditions caused by increased temperature captured in the atmosphere (hurricanes, severe storms) and others.[5] The economic impact of the emissions of one tonne of CO_2 is estimated to CZK 580 [5]– see Tab. 1.

Table 1: Unit external costs of pollutant emissions – CZK/t

Pollutant	Lower estimate*)	Upper estimate*)
NO_x	222,850	610,500
PM 2.5	976,850	2,777,900
SO_3	244,200	702,100
VOC	50,500	91,600
CO_2	580	580

*) The lower estimate is the impact on the countryside / the average impact on the CR; the upper estimate concerns waste in the urban area.

Source: Máca 2015 [5]

The European Parliament and Council Directive 1999/31/EC of 26 April 1999, on the landfilling of municipal waste, imposes on individual EU members states i.a. the obligation to develop a national strategy to reduce the deposition of biodegradable waste at landfills, because the conversion processes occurring in biodegradable waste in landfill bodies result in the production of biogas containing ca 30 vol. % of CO_2 and 70 vol. % of CH_4, which are gases with strong greenhouse effects [6].

For the assessment of the amount of the landfill or reactor biogas generated, a variety of models derived from theoretical and practically established data are currently used. For landfill processes with the aim of assessing landfill-gas generation, it is e.g. possible to apply the knowledge summarised in [7-12] which can be fully applied to faded cut flowers deposited at landfills.

2. Theoretical Relations

The amount of greenhouse gases from organic carbon substances produced in the anaerobic decomposition of biodegradable waste organic substances in landfill bodies can be determined e.g. by the general stoichiometric equation for organic substances with the molecular formula $C_xH_yO_z$, where x, y and z correspond to the numbers of atoms of individual elements[13] :

$$C_xH_yO_z + (x - y/4 - z/2)\ H_2O \rightarrow (x/2 + y/8 - z/4)\ CH_4 + (x/2 - y/8 + z/4)\ CO_2. \qquad (1)$$

In order to determine the overall impact of the landfill gas released from landfills into the atmosphere expressing its total radiation power calculated as the relative radiation power of carbon dioxide, it is necessary to multiply the amount of methane by the coefficient 34 based on its absorption efficiency and atmospheric lifetime[14].

The amount of CO_2 released into the atmosphere during transport has been calculated using a carbon calculator[15]. In the case of transport distance, the distance between the capital cities of the states concerned and the capital city of the CR – Prague has been applied[16].

3. The Components Monitored

The components monitored in this communication are biodegradable faded cut flowers, forming an inseparable part of municipal solid waste, i.e. the waste classifiable according to the Waste Catalogue[17] into the category 20, specifically the type, 20 02 01 – biodegradable waste, where municipal waste includes household waste as well as waste from trade, industry and institutions or other waste whose nature and composition is similar to household waste.

The calculations applied in this paper have been compiled for model simplification such that the total weight of the given waste produced annually in the CR is calculated from the number of cut flowers sold in the CR[18], which, having been used and faded, are deposited at landfills under anaerobic conditions.

The amounts of methane and carbon dioxide determined from Equation (1) are subsequently summed to obtain the total radiation power of CO_2 – see Equation (2)[14] :

$$CO_{2,\Sigma} = CO_2 + 34\ CH_4. \qquad (2)$$

For a general comparison, this amount of carbon dioxide, which would theoretically be generated from faded cut flowers during landfilling under anaerobic conditions, is calculated into the number of family houses, where the average annual consumption of natural gas for heating and hot water is estimated to be 2,500 m^3, or into the theoretical weight of the combusted typical wet brown coal containing carbon (22 wt. % of water, 25 wt. % of ash, 50 wt. % of carbon in the combustible matter) in the local furnace.

The power consumption necessary for the refrigeration of cooling devices based on their size, the length of storage and the amount of the flowers evaluated below can be estimated according to Whelan[21] by the equivalent of natural-gas consumption of 10,000 m^3. This amount of natural gas produces the same amount of carbon dioxide, i.e. calculated into 19,643 kg of CO_2.

3.1 Roses

Roses enjoy great interest in the CR. In 2015, their import into the CR was 3,107,099 kg [18], i.e. 109,281 kg of dry matter. More detailed characteristics of the import covering more than 14 countries, including domestic production, and the type of transport into the CR, including carbon-dioxide emissions associated with particular routes, are provided in Tab. 2. The elemental analysis of faded roses is given in Tab. 3.

Table 2: The import of roses into the CR and their transport

Country	Net [kg]	Air transport [km]	Lorry transport [km]	CO_2 [kg]	CO_2 [m^3]
Austria	492	0	331	13	7
Belgium	295	0	907	23	12
Bolivia	260	10,923	0	1690	860
Columbia	17,677	9,810	0	103,180	52,519
Ecuador	114,968	10,249	0	701,093	356,856.2
Ethiopia	28,958	5,079	0	87,511	44,543
Germany	448	0	682	25	13
Italy	665	1,308	0	72	37
Kenya	512,836	6,097	0	1,860,423	946,955.4
The Netherlands	2,260,440	883	0	164,681	83,823
Republic of South Africa	43	8,538	0	218	111.1884
Slovakia	165	0	333	5	2
United Kingdom	6,672	0	1,281	696	354
Other + CR	163,180	300 *)	1,000*)	42,590	21,678
Total	3,107,099	53,185	4,534	2,962,220	1,507,770

*) model transport distance
Source: UN Comtrade Database 2018 [18]

Table 3: The elemental composition of rose dry matter – wt. %

Element	C	H	N	$S_{comb.}$	Ash
Content	42.71	5.47	2.38	0.06	3.18

Source: author own calculations

Based on the equation received after the values from the elemental analysis shown in Tab. 2 are substituted in the formula (1):

$$C_{3,56}H_{5,47}O_{2,89} + 0.748\ H_2O = 1.741\ CH_4 + 1.819\ CO_2$$

The dry matter of cut roses produces the total amounts of methane and carbon dioxide listed in Tab. 4. This table also includes the total carbon-dioxide emissions associated with their transport and landfilling. Table 4 further shows the model conversion of this amount into the number of family houses using natural gas as the energy raw material, and the theoretical weight of the brown coal that would be converted through combustion into the given amount of carbon dioxide.

Table 4: The emission parameters of the faded cut roses deposited

Quantity	Unit	Value
The volume of the methane produced by 1 kg of faded roses	m^3	0.39
The volume of the carbon dioxide produced by 1 kg of faded roses	m^3	0.37
The weight of the methane produced by 1 kg of faded roses	kg	0.28
The weight of the carbon dioxide produced by 1 kg of faded roses	kg	0.74
The total weight of imported roses	kg	3,107,099
The total weight of the dry matter of domestic roses	kg	1,090,281
CH_4 from the rose dry matter deposited	m^3	414,827
CO_2 from the rose dry matter deposited	m^3	400,624
$CO_{2,\Sigma}$ from the rose dry matter deposited	m^3	14,504,745
$CO_{2,\Sigma}$ from the rose dry matter deposited	t	28,491.5
CO_2 from the transport	m^3	1,507,770
CO_2 from the transport	t	2,962.2
CO_2 from the cooling	m^3	10,000
CO_2 from the cooling	t	19.643
The total CO_2 emission	m^3	16,022,515
The total CO_2 emission	t	31,473
The number of family houses	pcs	6,409
Brown coal	t	23,527

Source: author own calculations

3.2 Carnations

Carnations are the second most popular flowers in the CR. In 2015, their import into the CR was 597,964 kg [18], i.e. 95,076 kg of dry matter. More detailed characteristics of the import covering 11 most important countries and the type of transport into the CR, including carbon-dioxide emissions associated with particular routes, are provided in Table 5[18]. The elemental analysis is given in Table. 5.

Table 5: The import of carnations into the CR and their transport

Country	Net [kg]	Air transport*) [km]	Lorry transport [km]	CO_2 [kg]	CO_2 [m^3]
Belgium	90	0	907	7	3
Columbia	22,119	9,810	0	129,108	65,716
Ecuador	9,212	10,249	0	56,176	28,594
Ethiopia	138	5,079	0	417	212
Germany	59	0	682	3	2
Italy	1,256	0	1,308	136	69
Kenya	2,045	6,097	0	7,419	3,776
The Netherlands	325,638	0	883	23,724	12,075
Portugal	284	0	2,246	53	27
Spain	381	0	1,355	43	22
United Kingdom	25,077	0	1281	2,617	1,332
Other + CR	211,665	300*)	1,000*)	55,245	28,119
Total	597,964	32,509	9,662	274,946	139,947

*) model transport distance
Source: UN Comtrade Database 2018 [18]

Table 6: The elemental composition of carnation dry matter – wt. %

Element	C	H	N	$S_{comb.}$	Ash
Content	42.72	5.47	2.34	0.10	8.33

Source: author own calculations

Based on the equation received after the values from the elemental analysis shown in Tab 6 are substituted in the formula (1):

$$C_{3,58}H_{5,94}O_{2,92} + 0.636\ H_2O = 1.803\ CH_4 + 1.775\ CO_2,$$

The dry matter of cut carnations produces the amounts of methane and carbon dioxide listed in Tab. 7.

This table shows the carbon-dioxide emissions associated with transport, the total radiation power of CO_2, i.e. the conversion of this amount into the number of family houses using natural gas as the energy raw material, and the theoretical weight of the brown coal that would be converted through combustion into the given amount of carbon dioxide.

Table 7: The emission parameters of the faded cut carnations deposited

Quantity	Unit	Value
The volume of the methane produced by 1 kg of faded carnations	m^3	0.40
The volume of the carbon dioxide produced by 1 kg of faded carnations	m^3	0.39
The weight of the methane produced by 1 kg of faded carnations	kg	0.29
The weight of the carbon dioxide produced by 1 kg of faded carnations	kg	0.77
The total weight of imported carnations	kg	597,964
The total weight of the dry matter of domestic carnations	kg	95,076
CH_4 from the carnation dry matter deposited	m^3	38,179
CO2 from the carnation dry matter deposited	m^3	37,587
$CO_{2,\ \Sigma}$ from the carnation dry matter deposited	m^3	1,335,689
$CO_{2,\ \Sigma}$ from the carnation dry matter deposited	t	2,623.7
CO_2 from the transport	m^3	139,947
CO_2 from the transport	t	275
CO_2 from the cooling	m^3	10,000
CO_2 from the cooling	t	19.643
The total CO_2 emission	m^3	1,485,636
The total CO_2 emission	t	2,919
The number of family houses	pcs	594
Brown coal	t	2,182

Source: author own calculations

3.3 Chrysanthemums

Chrysanthemums are the third most important imported cut flowers in the CR. In 2015, 1,930,670 kg were imported, or sold, here, which corresponds to 305,239 kg of dry matter[18]. More detailed characteristics of the import covering 10 countries and the type of transport into the CR, including carbon-dioxide emissions associated with particular routes, are provided in Tab. 9. The elemental analysis is given in Tab. 8[18].

Based on the equation received after the values from the elemental analysis shown in Tab 9 are substituted in the formula (1):

$$C_{3,78}H_{5,52}O_{2,52} + 1.14\ H_2O = 1.95\ CH_4 + 1.83\ CO_2,$$

the dry matter of cut chrysanthemums produces the amounts of methane and carbon dioxide listed in Tab. 10.

This table shows the carbon-dioxide emissions associated with transport, the total radiation power of CO_2, i.e. the conversion of this amount into the number of family houses using natural gas as the energy raw material, and the theoretical weight of the brown coal that would be converted through combustion into the given amount of carbon dioxide.

Table 8: The import of chrysanthemums into the CR and their transportation

Country	Net [kg]	Air transport [km]	Lorry transport [km]	CO_2 [kg]	CO_2 [m^3]
Austria	330	0	331	9	5
Belgium	30	0	907	2	1
Columbia	216	9,810	0	1,261	642
Ecuador	21,534	10,249	0	131,318	66,841
France	84	0	1,023	7	4
Germany	91	0	682	7	4
Italy	688	0	1,308	74	38
Kenya	64	6,097	0	232	118
The Netherlands	1,906,322	0	803	126,300	64,287
Poland	1,211	0	467	47	24
Other + CR	100	300*)	1,000*)	26	13
Total	1,930,607	36,266	6,521	259,284	131,975

*) model transport distance in the CR
Source: UN Comtrade Database 2018 [18]

Table 9: The elemental composition of chrysanthemum dry matter – wt. %

Element	C	H	N	S_{comb}	Ash
Content	41.75	5.52	2.72	0.07	9.62

Source: author own calculations

Table 10: The emission parameters of the faded cut chrysanthemums deposited

Quantity	Unit	Value
The volume of the methane produced by 1 kg of faded chrysanthemums	m^3	0.40
The volume of the carbon dioxide produced by 1 kg of faded chrysanthemums	m^3	0.39
The weight of the methane produced by 1 kg of faded chrysanthemums	kg	0.29
The weight of the carbon dioxide produced by 1 kg of faded chrysanthemums	kg	0.77
The total weight of imported chrysanthemums	kg	1,930,670
The total weight of the dry matter of domestic chrysanthemums	kg	305,239
CH_4 from the chrysanthemum dry matter deposited	m^3	133,328
CO_2 from the chrysanthemum dry matter deposited	m^3	124,371
$CO_{2,\Sigma}$ from the chrysanthemum dry matter deposited	m^3	4,657,537
$CO_{2,\Sigma}$ from the chrysanthemum dry matter deposited	t	9,148.7
CO_2 from the transport	m^3	131,975
CO_2 from the transport	t	259
CO_2 from the cooling	m^3	10,000
CO_2 from the cooling	t	19.643
The total CO_2 emission	m^3	4,799,512
The total CO_2 emission	t	9,428
The number of family houses	pcs	1,920
Brown coal	t	7,048

Source: author own calculations

4. Conclusion

The model study performed shows that it is necessary to limit the weight of the organic part of the biodegradable waste that has been landfilled so far, because the volume of the greenhouse gases, especially methane, produced by fermentation processes under anaerobic conditions at landfills, is non-negligible.

From the selected studied typical cut flowers bringing pleasure to our everyday lives, whose faded parts are commonly deposited at landfills, the highest amount of greenhouse gases is produced by roses, followed by chrysanthemums. The total emissions of methane from deposited roses is 0,14 mil m^3, from deposited chrysanthemums 0,13 mil m^3 and from carnations 0,04 mil m^3.

The total theoretical radiation activity of the greenhouse gases from the deposits of the three selected model types of cut flowers was 43,820 t of CO_2 – roses 31473 t, chrysanthemums 9428 t, carnations 2919 t.. Its total radiation power converted to the number of family houses using natural gas as the energy raw material would correspond to ca 8,923 family houses or 32,757 t of burnt brown coal. In this connection, it is advisable to include the use of landfill gases in the activities monitored within the legislation forming the framework of the EU energy policy concerning energy efficiency[19, 20].

The total unit external costs of the carbon-dioxide emissions of the three types ofmonitored cut flowers are CZK 25.4 mil, which would, however, be much higher if transport emissions were included in this balance. A future study should also focus on other emissions, especially VOC, NO_x and PM 2.5. Because of the scope of this work, this analysis focused on other pollutants has been omitted.

For the overall assessment of the landfilling of faded cut flowers in terms of environmental protection, the presented data should also be complemented by data focused on landfill water pollution by biocidal (bactericidal, disinfectant, fungicidal and preservative) agrochemicals, by which common cut flowers are treated to extend their life.

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Řezané květiny a produkce skleníkových plynů při skládkování biologicky rozložitelného komunálního odpadu

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Souhrn

Řezané květiny vytvářejí příjemnou atmosféru, ovlivňují estetický pocit vnímání mnoha životních situací. Bohužel vybledlé květiny končí na skládkách, kde podléhají anaerobnímu rozkladu a produkují značné množství skleníkových plynů. Jejich prodej je doprovázen leteckou i automobilovou dopravou a tak je také i distribuce květin zdrojem emisí oxidu uhličitého. Tento článek se věnuje přehledu skrytých ekologických souvislostí spojených se skleníkovými plyny u vybraných druhů řezaných květin.

Klíčová slova: *skleníkový plyn, komunální odpad, řezané květiny*

Analysis of a practical approach to the concept of sustainable development in a manufacturing company in the automotive sector

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Abstract

The sustainable operation of production enterprises can contribute to their attractiveness as well as strengthen their competitive position in the market. The implementation of these principles enables goods and services to be produced and provided in a way that uses processes and systems that reduce environmental impact. The article analyses the idea of sustainable development in building the value of a socially responsible production company. The aim of the article was to present the importance of sustainable development issues in relation to the functioning of one of the companies from the automotive sector and to conduct an analysis and demonstrate the benefits of designing and creating a department for secondary metal smelting - aluminum chip smelting.

Keywords: *production management, sustainable development, ecological motorization, ecological innovations*

Introduction

Human economic activity is inextricably linked to the transformation of the natural environment[1-3]. Originally, these changes were of a limited nature. However, with the progressive development of technology, technology and demographic explosion, the scale of emerging pollution began to pose a threat to the ecological balance on earth, as well as to the very ability of the environment to fulfil the necessary functions for the existence of people and to conduct all forms of economic activity[4-6]. It has therefore become necessary to establish international cooperation in the field of environmental protection. The manifestation of such actions is the emergence of the concept of sustainable development, as the only right way to further economic and social development[7]. This means managing economic activity in such a way that a balance is struck between human, economic and natural capital[8-10]. However, the implementation of sustainable development in a production company requires the integration of environmental and social issues into its management processes[11,12]. Hence, the aim of the article is to present ecological innovations as one of the tools supporting sustainable development and to analyse the implementation of the concept of sustainable development in a production company from the automotive sector.

The concept of sustainable development of manufacturing companies

Sustainable development is also referred to as eco-development, development: sustainable, continuous, integrated as well as sustainable growth defines the model of economic development, linking it to the requirements of environmental protection, thus satisfying not only consumer needs, but also the right of people to live in a clean environment. It is a process in which the needs of the presently functioning generation are satisfied, with the possibility of satisfying those needs by future generations[13-15]. It should be stressed that sustainable development assumes the interdependence of its three main areas (social, ecological, economic), as defined in the Revised EU Sustainable Development Strategy[16-18]. Manufacturing companies began to recognise that long-term sustainability helps to maximise profit. In this way, the relationship between social, environmental and economic governance is formed. At the same time, social order concerns the need for internal and intergenerational justice, while ecological order requires protection of available natural resources, while economic order manifests itself in satisfying the fundamental needs of humanity[19]. In this approach, sustainable development, for many manufacturing companies, has inspired the birth of a new approach to solving environmental problems, referred to as eco-innovations.

In the literature there are many definitions of the term "eco-innovation" as well as the concept of innovation itself, these innovations are a complex phenomenon. Many definitions of eco-innovation seem to be rather vague and therefore, according to the authors, many types of innovation can be attributed to the term eco-innovation[20].

Eco-innovations can be defined as new products and processes that provide value to business customers while reducing environmental impact[21,22,23]. Attention should be drawn to the position taken by the European Commission (EC), which in 2004 included ecological innovations in the category of environmental technologies, the use of which is less harmful to the natural environment than the use of alternative solutions[24,25,26]. However, three years later, the EC broadened the definition of eco-innovation to include all forms of innovation that aim to make visible and significant progress towards sustainable development, either by reducing negative environmental impacts or by achieving greater efficiency and responsible use of natural resources. In the EC's opinion, innovativeness refers both to services, production processes and management methods aimed at preventing or significantly reducing pollution and other negative consequences of the use of natural resources[5,14,27]. Several basic types of eco-innovation can be distinguished[9]:

- products - e. g. use of means of production of materials with rationalised characteristics;
- process - e. g. installation of new or improved production technology to reduce negative impact on the environment;
- organisational - e. g. implementation of the Environmental Management System (e. g. ISO 14000 series[28]);
- marketing - new marketing methods containing significant changes in the aspect of product packaging, its positioning, promotion, as well as price fixing (including the so-called ecological marketing).

A responsible production company can be defined as a company that strives to implement long-term ideas of sustainable development and growth through, among other things: a strong commitment to promoting social and environmental values or being responsible for the indirect (or direct) consequences of the functioning of economic activity[29,30]. A production company aspiring to the sustainable name should transform its existing paradigms of operation - from a traditional approach to sustainable development, as shown in Table 1.

The key aspect of the transformation of a production company towards sustainable development (Table 1) is to balance the idea of maximising profit (although it is important) in favour of creating new, intangible assets of the organisation, such as involvement in creating a strong brand and a positive image through environmental, social, ethical involvement and increasing the knowledge capital and functioning in harmony with nature as taking care of it and prudent use of natural resources. By flattening the rigid, hierarchical structure of the organisation and responsible decision-making, it will be possible to develop bottom-up ideas for sustainable development that are not doomed to failure due to the area of the uprising. When considering the manufactured products, apart from their functionality, significant attention is paid to their ecological character and intensive production system, which is characterized by innovation and development thanks to the reduction of raw materials and labour costs (increase in labour productivity). Attention is also drawn to the change in the approach to running a business from a vision correlated with the level of interest rates to a long-term vision, taking into account the potential needs of future generations. The change also affects the approach to products.

Table 1: Differences between a neoclassical production company and a sustainable production company

	Enterprise in neoclassical terms	Sustainability oriented company
Purpose	Maximising profit	Maximising profit with sustainability and growth, taking care of the environment and stakeholders
Product	Functional	Ecological - socially responsible
Production system	Extensive	Intensive
Organisation	Authoritarian, hierarchical, centralised	Networked, centralized, transparent, responsible decision making
Environment	The rule of nature	Harmony with nature
Vision	Correlated to the level of interest rates	Long-term, taking into account the needs of future generations
Value	Rational, material	Socio-economic, intangible

Source: own elaboration based on[8]

In the literature on the subject one can find studies indicating the positive influence of the implementation of the concept of sustainable development on ecological and social issues and on the processes implemented in enterprises[6,13,19,24,25].

Material and methodology

The analyzed production company, in accordance with the assumptions of sustainable development, has significantly modernized the infrastructure and the approach of both the management and employees to sustainable development. By translating the actions taken within the company into the development and interdependence of the three main areas of the concept of sustainable development (social, ecological and economic), the following actions have been taken:

- a department for the secondary smelting of non-ferrous metals and their alloys and the purification or processing of recycled metals (except for lead and cadmium) has been established,
- municipal management has been optimised by using, among other things, an automated waste collection system, which makes it possible to reduce the involvement of employees in the process (by 50%) and thus contribute to improving work safety,
- energy management has been optimised by implementing a water and heat recovery system that reduces the amount of raw materials used,
- ergonomic working conditions in the newly established department are ensured,
- within the framework of eco-innovation, the use of measures with rationalised characteristics in terms of environmental impact has been implemented in the area of product control (penetration testing),
- training was conducted to raise the awareness of employees about sustainable development and changes in the company related to this concept.

The undertaken activities related to the implementation of the concept of sustainable development in the company have contributed to the creation of a complex network of relations between the indicated areas, which results in a significant reduction of the negative impact on the human living environment, cost reduction (e. G. in the field of municipal management up to 80%) and optimization of work logistics and increasing environmental awareness of employees.

The company's activities in the field of sustainable development have been presented on the example of the department of secondary metal smelting - aluminium chip smelting. The course of the melting process is shown in Figure 1.

The efficiency of the production alloys melting in the newly opened department is based on early adaptation of the chemical composition of the aluminium alloy to production needs. In the company submitted, the alloys used for production do not have standard equivalents, which makes it necessary to melt and modify the composition within the company and the material you acquire is a process re-melting.

Storage of aluminium and aluminium chips intended for secondary smelting is carried out in a separate hall, in boxes and containers with a sealed base, respectively. Aluminium chips come from the company's production (machining departments). Dry aluminium alloys, i. e. aluminium electric cables without casings, come from approved suppliers (in accordance with the Quality Management System procedure). Other raw materials - additives, modifiers and input materials are stored in appropriate storage rooms.

Chips transported in tight containers from the production hall are intended for preliminary cleaning. In the next stage, the cleaned chips are transported to a metal separator operating according to the principle of magnetic field - attracting all ferromagnetic metal parts, i. e. rings, cutting inserts. Then the chips are transferred to the shredding unit and through a feeder to the centrifuge (separation of chips from processing oil and water). The dried chips are sent to three magnetic separators, where all dusty fractions and small chips (<1 mm) are vibratively separated. Separated swarf goes to the tumble dryer, where it is additionally dried with hot air.

Preheated chips with a moisture content of less than 1.5% are fed into the FUS/20/PB/M melting furnace together with a flux cleaning and covering Flux Test Flux at a rate of 1% in relation to the number of chips. After remelting, a chemical composition test shall be carried out and, if necessary, corrected by the addition of appropriate alloying elements.

During the pouring of the liquid alloy from the ladle furnace, the Coveral MTS 1565 flux is, dosed directly onto the metal stream, and then the metal is refined to refine the liquid metal with a mixture of argon - chlorine to degasify the alloy. Refining takes place at a temperature of approx. 800 ºC.

After the refining process is completed, the degree of gasification of the alloy is checked. If the result is in accordance with the applicable standards, the liquid alloy is transferred to the heating furnaces, while the surplus is directed to the casting line of the bar – “gąski”. After being poured into a mould, the alloy is cooled with water and stamped. After being stamped and cooled, the caterpillars broken from the moulds are transferred to the storage place, to a properly separated caterpillar warehouse.

Finished dry aluminium alloys and other raw materials of a density and size adapted to the type and parameters of the furnaces used, are remelted in gas or induction furnaces with combustion control and recuperation with sealed closing covers. Parameters of exemplary furnaces placed in the foundry are presented in Table 2.

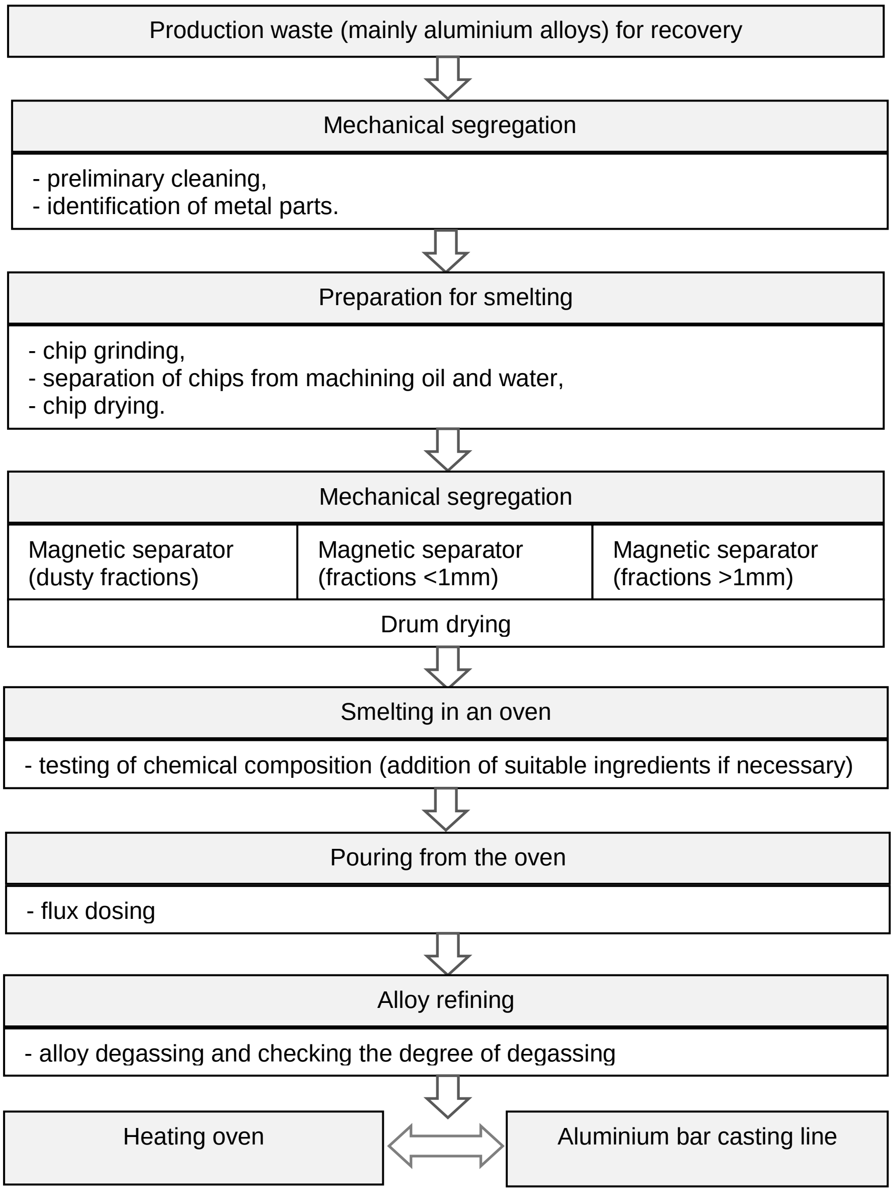

Figure 1: Secondary aluminium smelting process

Table 2: Parameters of exemplary technological equipment of piston production lines

Parameters	**Induction furnace type PIT-1000**	**Induction furnace Junker type MFT Al 1500**	**Parameters**	**Gas stove STRICO**	**Gas stove PO 6000**
Capacity [Mg]	1,0	1,5	Capacity [Mg]	1,0	6,0
Maximum power [kW]	350	800	Maximum heat output [MW]	0,8	1,2
Energy consumption [kWh/1 Mg Al.]	500	585	Operating temperature [^{o}C]	820	820
Melting speed kg Al/h	300	800	Melting rate [kg/h]	400	1000
Melting temperature [^{o}C]	880 – 900	820	Maximum gas demand [m^3/h]	179	220

Thanks to the availability of various melting furnaces and other necessary equipment within the company, it is possible to optimise melting processes in order to minimise the negative impact on the environment. Such technological flexibility is not available in melting processes involving other materials or standard technologies[9].

Other alloys, i. e. production waste, are also subject to secondary smelting. Their types and the amount allocated to the disk are presented in Table 3.

Table 3: Permitted types and quantities of waste destined for recovery

No.	Type of waste destined for recovery	Quantity of waste destined for recovery [t/year]
1.	Defective cast iron products	15
2.	Wastes from turning and sawing of iron and its alloys	1700
3.	Wastes from turning and sawing of non-ferrous metals	10000
4.	Copper, bronze, brass	100
5.	Aluminium	1500
6.	Iron and steel	300
7.	Wastes not otherwise specified	1000

The values in Table 3 show the comprehensive nature of the remelting technology used in the newly established remelting department. The possibilities of re-melting the indicated waste contributed to the optimisation of production waste management.

The secondary smelting hall is equipped with technical measures to reduce emissions of pollutants into the air - general ventilation, which enables natural convection of fumes and fumes. Ventilation uses ventilation slots located on the walls of the building. The melting furnaces are equipped with extraction hoods and the gases caught by them are discharged to the outside by means of emitters. For induction furnaces PIT-1000 and MFT AL. In the case of the 1500, a common system of gas discharge has been applied, in which the extracted dust and fluorine compounds are discharged by means of hoods to a common emitter. Pollutants from the refining station are discharged to the emitters by means of hoods.

Results and discussion

Previously, the company had not conducted such advanced pro-ecological activities. The proposed and implemented concept of the authors is a novelty within the company. The reorganisation of the infrastructure and the creation of a secondary smelting department and the installation of technical measures to reduce air pollutant emissions contributed to the decrease in emissions (Table 4).

The data contained in Table 4 indicate a reduction in the emission of pollutants after the implementation of the secondary metal smelting process - aluminium chips smelting. The data confirms the usefulness and effectiveness of the implemented technology.

Monitoring of technological processes in the company is carried out on the basis of processes, procedures and instructions binding on the premises of the company as part of the Environmental Management System functioning in the company, which is consistent with the requirements of PN-EN-ISO 14001 and PN-N 18001.

Table 4: Comparison of annual emissions before and after the installation of technical measures to reduce emissions of pollutants into the air after the establishment of the secondary smelting division

No.	Type of pollutant	Emissions before installation of technical measures [t/year]	Emissions after installation of technical measures [t/year]
1.	Total dust	21,739	18,062
2.	PM 10 particulate matter	21,739	18,062
3.	Sulphur dioxide	8,003	7,977
4.	Nitrogen oxides	71,067	69,717
5.	Carbon monoxide	25,899	25,484
6.	Fenor	0,290	0,299
7.	Fluorine	1,006	0,781
8.	Formaldehyde	0,123	0,123
9.	Sulphuric acid	1,22	1,22
10.	Hydrogen chloride	3,371	2,559
11.	Tin and its compounds	0,812	0,0065
12	Acyclic hydrocarbons	0,0065	0,00156
13.	Aromatic hydrocarbons	1,611	0,00156

In accordance with the “Environmental Monitoring and Measurement Schedule" which is an annex to the “Monitoring and Measurement" Procedure, the production of waste, emission of gaseous and particulate pollutants, as well as water consumption, production of industrial sewage, industrial and household sewage, consumption of gas, electricity, and monitoring of the working environment are monitored.

The introduction of the secondary smelting method in a company affects both the so-called environmental pillar and the economic pillar. Table 5 shows the percentage rate of savings from smelting and recovery of production alloys.

Table 5: Savings on smelting and recovery of production alloys after the establishment of the secondary smelting department over three quarters

Lp.	Type of waste destined for recovery	Saving [%]		
		I quarter	II quarter	III quaeter
1.	Defective cast iron products	17,21	18,89	17,97
2.	Wastes from turning and sawing of iron and its alloys	8,77	9,05	8,80
3.	Wastes from turning and sawing of non-ferrous metals	11,45	11,20	12,06
4.	Copper, bronze, brass	3,02	2,91	2,78
5.	Aluminium	26,59	27,77	26,34
6.	Iron and steel	9,24	8,86	8,12
7.	Wastes not otherwise specified	5,01	4,79	7,70

On the basis of the data contained in Table 5, it can be seen that the savings, in the quarterly settlement, from melting and recovery of post-production alloys reach the highest values in the case of aluminium (26. 34% - 27. 77%). The data confirms the usefulness of the new solution which has been made more expensive in the company.

In addition, the choice of the optimal distribution of the smelting department contributed to the optimisation of work logistics and the dissemination of the recycling concept in the area of the company, which contributed to the rapid acceptance of pro-environmental changes introduced in the company.

Due to the volume limitation, the influence of the company on the emission of gaseous and particulate pollutants, water consumption, production of industrial sewage, industrial and household sewage, gas consumption, electricity consumption was not taken into account in the work.

In accordance with the idea of sustainable development, the analyzed company within the framework of pro-environmental activities continuously implements activities in the area of main pillars of the concept of sustainable development. The pro-ecological activities undertaken in the company have no clear boundaries between the main pillars of the concept of sustainable development, because one action (change) generates effects, e. g. from 2 or 3 planes. This includes:

- in the economic and organizational area:
  - Rigorous adherence to technology procedures that maximize the production of good quality products and thus minimize production waste. Developing and applying procedures relating to the management of raw materials and production materials.
  - The quality level of supplied raw materials is supervised by the Delivery Quality Control. The condition of the delivery is checked in terms of material approval, the surface condition of the goose, the weight of the delivery, the condition of packaging and marking on the goose), as well as the chemical composition, microstructure of the goose, hardness and strength of the input materials are checked in accordance with accepted standards.
- in the economic and environmental area:
  - In the production process of pistons, the use of raw batch material with a defined and controlled alloy composition, in the form of pure aluminium goose, missing castings in the amount of not more than 50% of the batch material and additives in accordance with technological instructions for melting the alloys.
  - Taking action to reduce the amount of waste generated, e. g: prevention of losses of raw materials, materials, products and semi-finished products, observance of technological process parameters, use of auxiliary materials of the highest quality, analysis of input materials - analysis of safety data sheets, pro-ecological planning of technological processes.
  - Maintain all equipment in good working order and operate it properly in accordance with the technical and operating instructions.
- in the environmental area:
  - Development and implementation of a programme to reduce the amount of hazardous waste produced.
  - In order to reduce fugitive emissions of pollutants into the air, the removal of the waste from the production sites is carried out after they have completely cooled down.
  - Control emissions, water and energy consumption and take immediate corrective action if they are found to be exceeded.
- in the social area:
  - Keeping roads, squares and the remaining area clean and tidy Installing sound-absorbing covers on the hall fans.
  - Permanent surveillance of working conditions.

The presented data confirm the effectiveness of the concept of metal re-melting implemented by the authors. The main advantages of the new solution used in the company include the reduction of pollutant emissions and significant savings, on a quarterly basis, from smelting and recovery of post-production alloys, which in the case of aluminium reach values of 26. 34% - 27. 77%. It is also important to design the melting process properly and to ensure the availability within the company of different melting furnaces together with other necessary equipment, it is possible to optimise the melting processes in such a way as to minimise the negative impact on the environment.

Summary

The new market challenges faced by economic operators mean that they operate in accordance with the idea of sustainable development. All actions resulting in the minimisation of negative impact on the natural environment undertaken by enterprises can be considered as a manifestation of the implementation of the idea of sustainable development. In this way, companies contribute to the preservation of the quantity and quality of natural capital, which is the basis for meeting the needs of present and future generations and adapting the scale of the functioning economy to the ecosystem on which it operates.

The functioning of companies in accordance with the idea of sustainable development is a long-term process, which is connected with the need to develop the awareness of the management of companies operating on the market. The integration of environmental and social aspects into the management of economic operators is linked to the need to incur expenditure on environmental protection and to support community-based initiatives. This measure increases the company's costs and at the same time reduces short-term profits. However, in the long term, it has a positive impact on increasing the competitiveness of the company by creating a new image that allows to acquire new and maintain existing customers. The understanding of the presented dependencies by entities operating on the Polish market is extremely important in the context of their persistence and further development.

An example of an organization realizing the idea of sustainable development is the analyzed company producing pistons for internal combustion engines. Previously, such advanced pro-environmental activities were not carried out in the company. The proposed and implemented concept of the authors is a novelty within the company. The main advantages of the new solution used in the company include the reduction of pollutant emissions and significant savings, due to remelting and recovery of post-production alloys.

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Analýza prístupu ku koncepcii udržateľného rozvoja vo výrobe v automobilovom sektore

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Summary

Fungovanie spoločnosti v súlade s myšlienkou udržateľného rozvoja je dlhodobý proces, ktorý súvisí s potrebou rozvíjať povedomie o riadení spoločností pôsobiacich na trhu. Integrácia environmentálnych a sociálnych aspektov do riadenia hospodárskych subjektov súvisí s potrebou vynaložiť náklady na ochranu životného prostredia a s podporou iniciatív na úrovni komunitného spoločenstva. Toto opatrenie zvyšuje náklady spoločnosti a zároveň znižuje krátkodobé zisky. Pochopenie prezentovaných závislostí subjektmi pôsobiacimi na poľskom trhu je mimoriadne dôležité v kontexte ich pretrvávania a ďalšieho rozvoja. Príkladom organizácie realizujúcej myšlienku udržateľného rozvoja je analyzovaná spoločnosť vyrábajúca piesty pre spaľovacie motory. Predtým sa také pokročilé proenvironmentálne činnosti v spoločnosti nevykonávali. Navrhovaná a implementovaná koncepcia autorov je v spoločnosti novinkou. Medzi hlavné výhody nového riešenia používaného v spoločnosti patrí znižovanie emisií znečisťujúcich látok ako aj výrazné úspory v dôsledku pretavovania a spätného získavania postprodukčných zliatin.

***Keywords**: riadenie výroby, udržateľný rozvoj, ekologická motorizácia, ekologické inovácie*

Numerical and Experimental Investigation of the Effect of the Mineral Wastewater and Improved Dune Sand Subgrade and Pavement Rutting

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Abstract

Nowadays, along with an increase in mine activities, pay attention to environmental issues to achieve the sustainable targets has gained a special place. On the other hand, an increase in various types of natural destructive pollutants and also increasing the use of industrial and drinking water by human societies is deniable. Using mineral wastewater and mine tailings in road and building construction projects will provide great help for the environment. In the present study, stabilization of dune sand, which is one of the loose soils in road construction projects, has been investigated using a kind of mineral wastewater at three weights 7, 14 and 21 percentages by dry weight of soil. For this purpose, compaction, compressive strength, direct shear and CBR tests have been done to investigate the effect of this material on the resistance parameters of dune sand. The results showed that the addition of mineral wastewater to the soil, led to a decrease and an increase in optimum moisture content and maximum dry density, respectively. The addition of mineral wastewater increases the compressive strength and displacement and as a result of an increase in the weight percentage of mineral wastewater, the number and the depth of failure cracks have been reduced Increase the mineral *wastewater from 14 to 35%, has led to an increase in compressive strength of more than 39%. By checking the SEM images, it was found that the reduction in the holes and porosity of the soil, as well as an increase in interlocking between the particles, are the factors of increase in strength parameters. To investigate the application of this method in road construction, the effect of stabilized layer and the mineral wastewater content of the settlement has been studied. The results of numerical analysis show that add 7 and 14 percent of mineral wastewater reduces the settlement compared with unstabilized sample. Therefore, the probability of rutting failure of subgrade will be reduced. Finally, the recommended function of Response Surface Methodogly for settlement in terms of the two variables includes layer width and mineral wastewater content has been defined using the response level analysis method.*

Keywords: *Mineral wastewater, subgrade stabilization, shear strength, compressive strength, dune sand, rutting.*

Index of abbreviations

CBR	California Bearing Ratio(%)	φ	Friction angle of soil(°)
ω_{Opt}	Optimum Water(Moisture) Content(%)	SEM	Scanning electron microscope
$\gamma_{d,max}$	Maximum Dry Density(gr / cm^3 or kN/m^3)	XRF	X-Ray Fluorescence
G_s	Specific Gravity of Soil	FTIR	Fourier Transform Infrared Spectroscopy
C	Cohesion of soil (kPa)		

1. Introduction

Expanding the waste materials application in developing projects are of those activities which no only reduce the costs but also will help preserve the environment. Various materials such as lime, cement and some polymer materials have been used by researchers for stabilizing the soil [1-8]. Recycle asphalt pavement, crushed tile and ceramic are of those waste materials which have been used in road construction building projects which have desirable results in stabilization and improvement of soil. Repair and maintenance, pavement reconstruction and resurfacing in order for increasing the annual productivity and efficiency will produce a large amount of recycled pavement asphalt [9]. Use of recycled pavement asphalt has increased the soil strength [10] and has been recommended as a good choice for a base or subbase layers or stabilizing the soil of these layers [11-14]. Combination of recycled pavement asphalt with other stabilizers such as cement or fly ash has increased the compression strength and bearing capacity of soil of crushed stone aggregate [15-18].Crushed ceramic is also another kind of the waste materials which has the desirable effect on increasing the concrete compression strength [19]and on increasing the compression strength of clay soil stabilized with cement as the subbase layer [20]. Crushed ceramic in the expansive soil[21-24] and in the black cotton soil (Raghundeep et al. 2015) has increased the resistance parameters so that these soils become desirable to be used in the road construction projects. Crushed ceramic in the clay soil has also increased the bearing capacity [25]. Ameta et al (2013) by performing the CBR and direct shear tests on the dune sand stabilized with crushed tile, observed an improvement in bearing capacity and strength parameters of dune sand [26].

The effect of coal on the pavement performance has been investigated by Saberian and Khabiri, 2017 [27]. The addition of the coal has increased the compression strength and bearing capacity and the coal up to 4 percent has increased the safety factor of embankment slope.Ojuri et al (2017) evaluated the effect of the lime-cement binder on the strength of soil mixed with mine tailing. The aim of their research was the evaluating the effect of the application of this mixture in highway construction. Their results showed that the CBR increases with increase in both mine tailing content and lime-cement content. Also, increase in lime-cement content and curing time has led to increase in compression strength and CBR[28].

The addition of 20% of waste materials has increased the compressive strain and rutting depth. Addition of construction waste materials and stabilizing it with lime despite of reducing the rutting depth, also will increase the lifetime of asphalt [29].

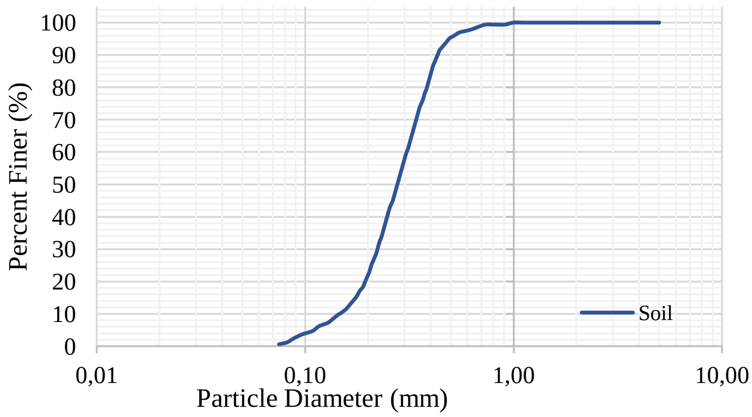
In the present study, mineral waste water has been used to stabilize the dune sand. Dune sand is one of the most common soil in the desert area which has not a proper bearing ratio for road construction projects. Therefore, addressing the stabilization and improvement of this type of soil is of great importance. On the other hand, using industrial wastewater, including wastewater used in the present study, is effective and helpful activity in environmental view. In order to investigate the stability of dune sand with mineral wastewater compression, direct shear and CBR tests have been used.

2. Material and Methods

In this study, the stability of the dune sand using mineral wastewater has been investigated. First, the tests related to particle-size analysis, measurement of Atterberg limits and compaction characteristics of dune sand and mineral wastewater has been examined. The standard related to these tests is provided in Table 1. After that, to investigate the effect of these kind of stabilization on the soil strength, direct shear and CBR test have been used which have been performed based on the ASTM D-3080 [30]and ASTM D-1883 [31], respectively. Finally, SEM images have been used to investigate how the mineral wastewater executed in soil stabilization and subgrade strength increase.

2.1. *Dune sand*

Based on the AASHTO category, the soil used in the present study was classified as fine sand (A-3). After performing the soil recognition tests, gradation curve and some of the mechanical properties and specifications of testing soil are shown in Fig.1 and Table 1, respectively. Fig.2 shows an image of sand used and the dimensions of soil operations related to pavement and road construction.



(a)

Fig. 1: The gradation curve of soil used in the present study.

(a) (b)

Fig. 2: (a) The volume of soil operation; (b) The location of harvesting the sand sample and mineral wastewater used

Table 1: The specifications of soil used in the present study.

Parameter	Content	Unit	Standard used
Soil classification	A-3	-	AASHTO
G_s	2.7	-	ASTM D-854
CBR	28.5	(%)	ASTM D-1883
C	0.1	(kPa)	ASTM D-3080
φ	46	(degree)	ASTM D-3080
ω_{Opt}	16	(%)	ASTM D-698
γ_{max}	1.845	(gr/cm^3)	ASTM D-698

The results of identifying the elements of the materials used were extracted by the XRF method in accordance with reference studies [32], Therefore, the chemical components of sand used in the geographical area of this research is presented as an average in Table (2).

Table 2: Identification of chemical elements of quicksand (mean) in the study area by XRF method

Detected element	Quantity (%)
SiO_2	48
Al_2O_3	8.3
MgO	4.5
P_2O_3	14
TiO_2	8
MnO	0.1
CaO	22.5
Na_2O	0.8
K2O	19
Others	8.5

2.2. Mineral wastewater

The stabilizer material used in the present study is a kind of mineral wastewater that after being dry and dissipation of moisture has been used as the stabilizer material. These materials were obtained from metal factories and mines around Bafgh. The raw materials, which were in the form of slurry, were collected from the sewage canal and then dried in the laboratory in the oven. Fig. 3 shows the gradation curve of the mineral wastewater which was performed by hydrometer test and based on the ASTM D-442 standard [33]. Fig.4 shows the image of mineral wastewater. Based on the ASTM D-4318 [34] standard the liquid limit and plastic limit of mineral wastewater were measured at 25.72 and 16.64, respectively. The average, the maximum and the minimum of the element concentrations in the mineral wastewater sedimentation sample were listed in the Table 3.

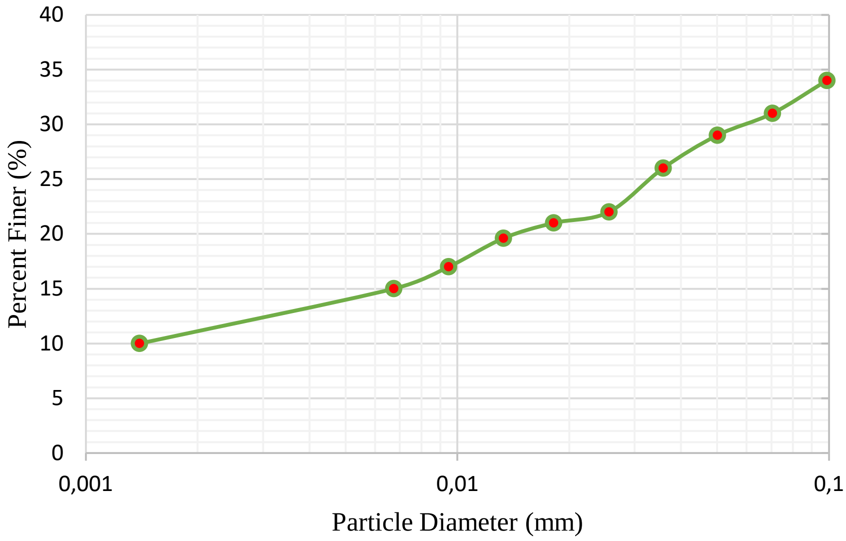


Fig. 3: The gradation curve of the mineral wastewater

Fig.4: The mineral wastewater alongside the dune sand

Table 3: Average, maximum and minimum amount of components in mineral wastewater used in research [35]

Variable	Maximum(ppm)	Minimum (ppm)	Average (ppm)
Ag	0.26	0.2	0.223
Al	26421	26419	26419.96
As	27.17	26.8	27.016
Be	2.8	2.2	2.52
Cd	0.3	0.24	0.275
Co	56.1	55.6	55.896
Cr	50.9	49.8	50.089
Cu	35.1	33.9	34.84
Mn	744	742	743.022
Mo	1.84	1.59	1.685
Pb	34.32	33	33.909
Se	0.53	0.5	0.514
V	449.92	448.8	449.149

2.3. Sample preparation

To create the test samples, dry dune sand was mixed with 0, 7, 14 and 21 percent of mineral wastewater content that named SP100, SP93, SP86 and SP79 in text, respectively. Samples were prepared in the optimum moisture content and the maximum dry density results from compaction test. To prevent the variation of samples moisture, they must be kept in a closed environment.

For determination of subgrade mechanical properties as well as the C.B.R and Shear resistance, tests were conducted on a modified sand soils which is characterized by sieve analysis (ASTM D1921) to see the particle size distribution of the soil. In the present study, the situation of the compacted subgrade for highway constructions was simulated by performing tests on compacted samples. Samples were prepared by modified compaction (ASTM D698) for California Bearing Ratio tests (ASTM D1883). For many countries, where resources are at a premium, it is actual important that stabilized resident soil can be used for pavement subgrade. To make sure that modified sand can be used for pavement material standard compact on and CBR tests were implemented.

3. Results and discussion

3.1. Compaction test results

To measure the optimal moisture and the maximum dry density, weight of stabilized samples the density test was used. The compaction curve of samples with 0, 7, 14 and 21 percent of mineral wastewater content is shown in Fig. 5. By increase in the mineral wastewater content in soil, the dry density weight has increased. The addition of the mineral wastewater to the soil reduced the optimum moisture, but the certain trend between reductions in the moisture and increase in mineral wastewater was not observed. Adding of additive has reduced the porosity of the soil, due to the finer grains than dune sand, which can cause to a decrease in the moisture and in an increase in the dry density weight of the soil. Results are shown in Table 4.

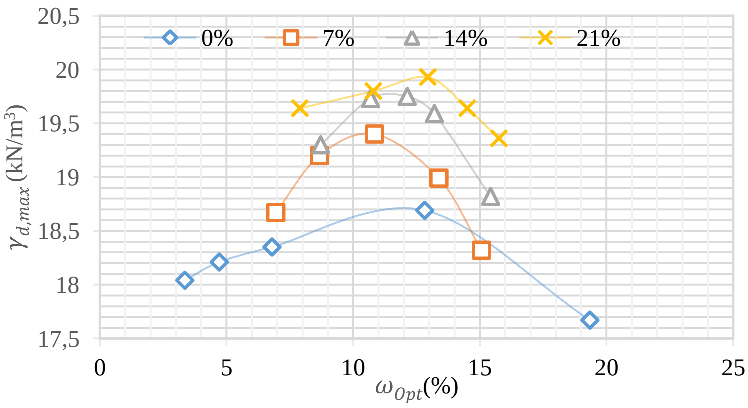


Fig. 5: Compaction curve of dune sand stabilized with different contents of the mineral wastewater

Table 4: Results of the compression test

Samples name	Mineral Waste (%)	$\omega_{Opt}(\%)$	$\gamma_{d,max}(\frac{kN}{m^3})$
SP 100	0	12.7	18.6
SP 93	7	10.75	19.4
SP 86	14	12	19.75
SP 79	21	12.5	19.95

3.2. The uniaxial compressive strength test result

To investigate the effect of the mineral water on the shear strength of the dune sand, the uniaxial compression test was used. To make use of this test, the 14 to 35 percent of mineral wastewater has been used in the soil so that the required adhesion to create the sample is obtained. Fig.6 shows the results of the compressive strength test. As it is clear from the figure, an increase in the wastewater content in the soil has increased both the compressive strength and failure deformation. Fig.8 shows an image of the samples stabilized with the mineral wastewater. According to the figure it is clear that an increase in the mineral content in the soil has increased the adhesion and interlocking between the particles and the more integrated structure has been obtained that not only increase the compressive strength, but also decreases the cracks created after the failure. In the sample stabilized with 14% of mineral wastewater content, the failure sample has more and deeper cracks than the sample stabilized with 35% of the mineral wastewater content. Therefore, increase in wastewater content in the dune sand has increased the deformability of the soil. Some of the cracks created in the samples after the failure has been indicated in Fig. 7.

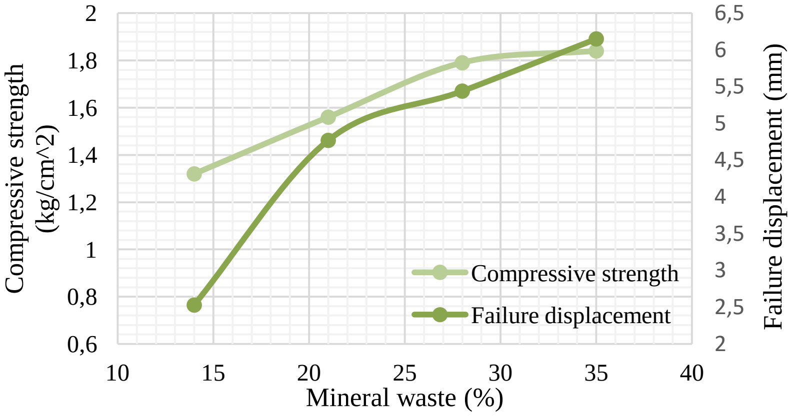


Fig.6: Shear strength of the dune sand samples stabilized with mineral wastewater

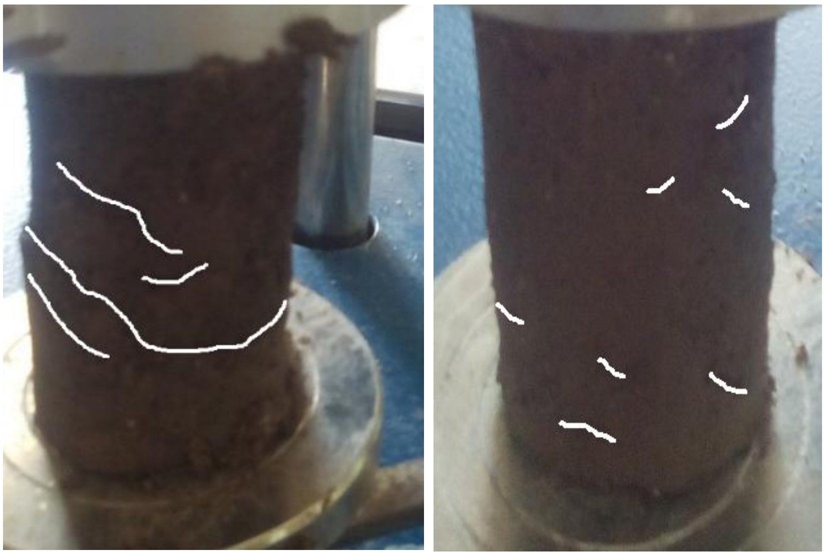


Fig.7: Stabilized sample after compressive strength test. (Left): the sample stabilized with 14% of the mineral wastewater content and (Right): the sample stabilized with 35% of the mineral wastewater content

3.3. Direct shear test results

Direct shear test for stabilized and non-stabilized samples has been performed for normal stresses of 55, 111 and 222 kPa. The results are shown in Figs (8-10). At normal stresses of 55 and 111 kPa, by adding the mineral wastewater, the shear strength has increased but at normal stress of 222kPa addition of the mineral wastewater has no effect on the increase in the shear strength. Therefore, at high normal stresses, the effect of the addition of the mineral wastewater on the increasing the shear strength has decreased. The maximum increase in shear strength in stabilized sample with 21% of wastewater content and at normal stress of 50 kPa was found to be about 44%.

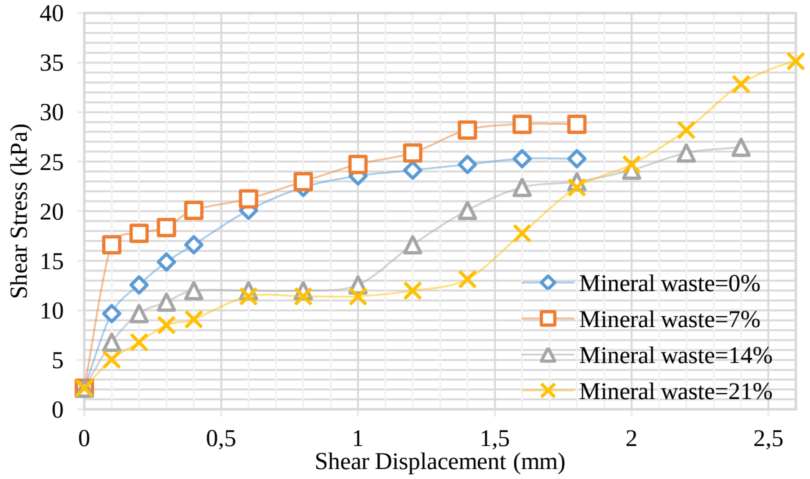


Fig. 8: Shear displacement-shear stress curve of stabilized soil with mineral wastewater at normal stress 55 kPa

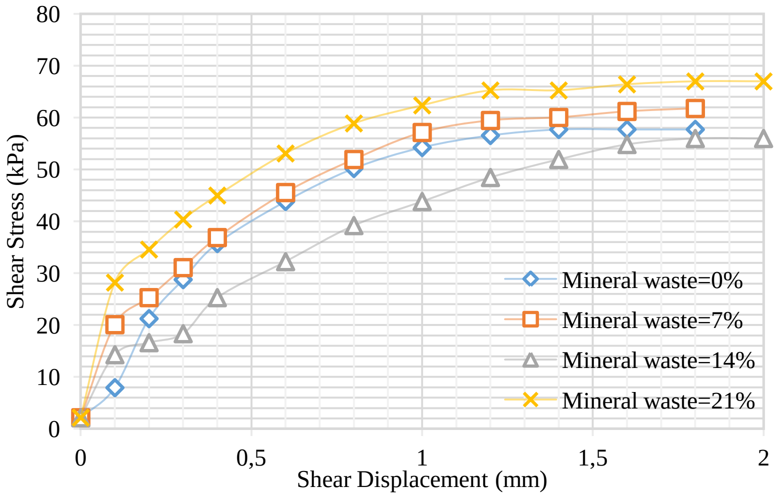


Fig. 9: Shear displacement-shear stress curve of stabilized soil with mineral wastewater at normal stress 111 kPa

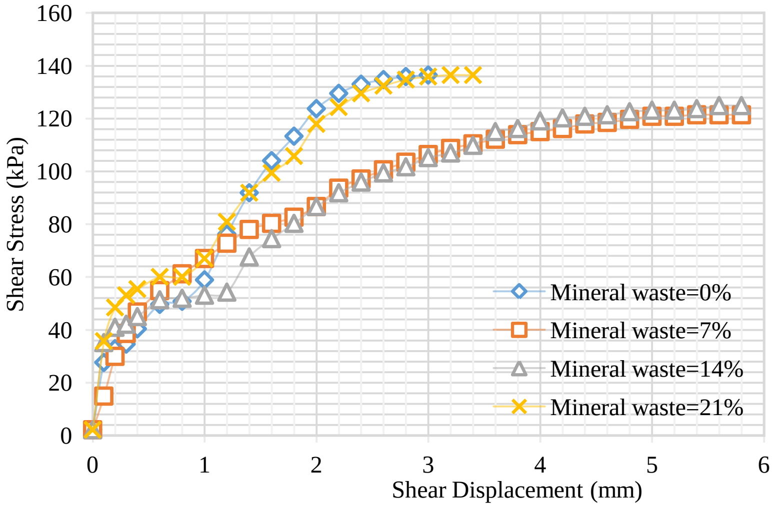


Fig.10: Shear displacement-shear stress curve of stabilized soil with mineral wastewater at normal stress 222 kPa

3.4. CBR test results

One of the important tests in pavement project, is CBR test. The addition of 7% of mineral wastewater content to dune sand has increased the CBR up to 58%. By increasing the mineral wastewater content, the bearing capacity has decreased so that at 21% of mineral wastewater content has reached the bearing capacity lower than that of the non-stabilized soil. Fig .11 shows this trend. As can be seen from the figure, cubic equation is also calculated in terms of the wastewater content in the soil.

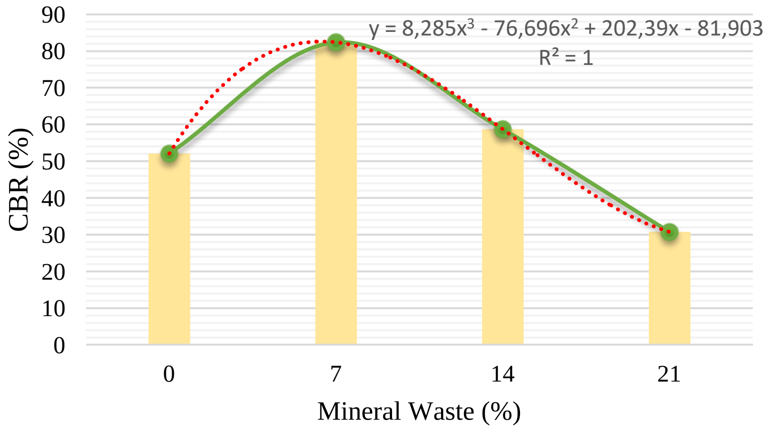


Fig. 11: CBR of the tested samples

3.5. Microscopic examination of specimens

Fig. 12 shows the SEM images of the stabilized samples. By adding mineral wastewater to the soil, the holes between the particles reduces and interlocking between them increases. In this image, the interconnection and adhesion of the materials to each other is quite clear compared to sand grains. Due to the adhesion property of the mineral wastewater compare with dune sand, the soil components compressed and interconnected after the stabilization and as a result the soil structure becomes more compressed. These variations in soil increases the maximum dry density weight, strength and bearing capacity of the soil which are in agreement with experimental results of this study.

Figure 13 shows the FTIR analysis of of mixture of sand and wastewater. According to the results obtained from this analysis, it was found that the highest absorption spectrum is 3578 cm^{-1}, which is related to the presence of tensile O-H from the group of alcohols and has an absorption percentage close to 100. The absorption spectra of 2364 cm^{-1} are related to the presence of C-O chain and also the absorption spectra of 2014 cm^{-1} and 2168 cm^{-1} are related to the presence of tensile C=C from the group of alkenes and C=C vibration from the group of alkynes, respectively. Also, according to the figure, it was observed that the absorption spectrum of 1421 cm^{-1} related to C=O tensile from the aromatic ring and the absorption spectrum of 999 cm^{-1} and 873 cm-^{1}, respectively, related to the presence of tensile C-O from the group of alcohols and = C– H is a stretch of the group of alkenes. Finally, the last absorption spectrum is 645 cm-1, which is related to the presence of vibratory C-H.

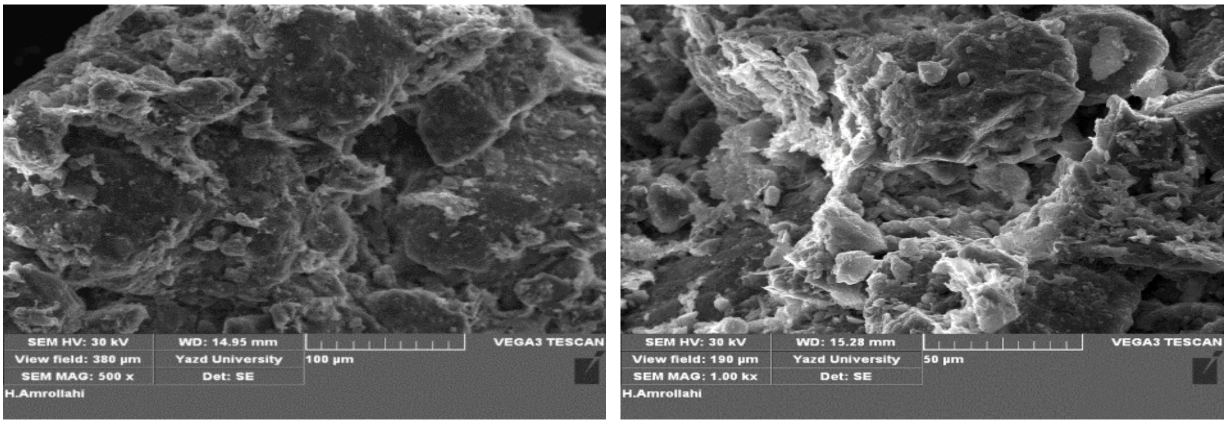


Fig. 12: SEM images of dune sand samples stabilized with mineral wastewater

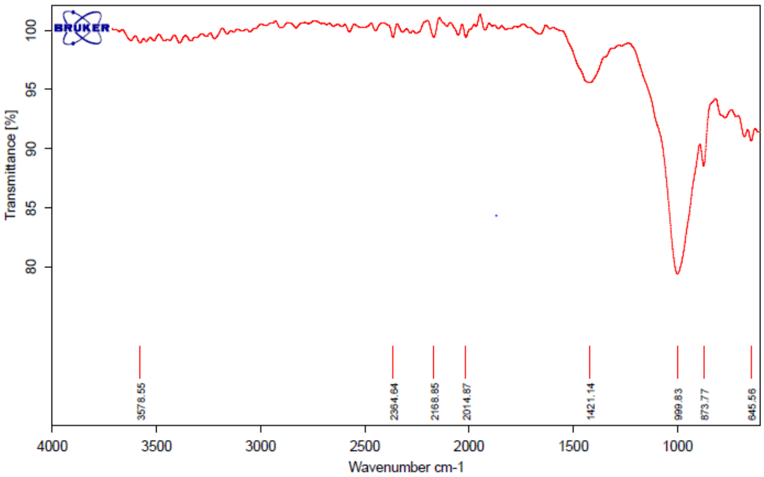


Fig. 13: FTIR spectra of stabilized soil samples

3.6. The pavement settlement in numerical modeling

The pavement settlement was modeled using EverStress software and the effect of the subgrade improvement on the settlement has been investigated. Fig.14 shows the meshing used in the model and the strain contour obtained from the modeling.

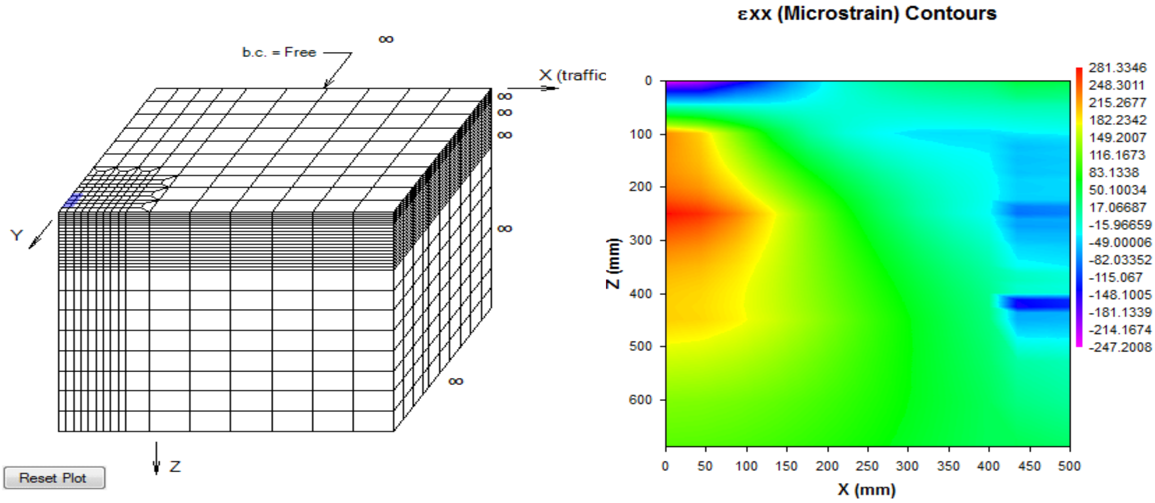


Fig. 14: (Left): Meshing in numerical software; (Right): Strain contour result from designed subgrade in software

Fig. 15 shows a 3D plot of the settlement in terms of two variable layer width and the mineral wastewater content using the MATLAB software. The amount of the settlement in the sample without stabilization was estimated to be 467.9µm, which comparing with results related to stabilized layers with this value shows that at all widths, the layer stabilized with 21% of the mineral wastewater content has more settlement than that of the non-stabilized soil. In the layer stabilized with 7and 14 percentage of mineral wastewater content the settlement has reduced compared with than that of the non-stabilized sample. At constant wastewater content, by increasing the width of the stabilized layer the certain trend in reduce or increase in the settlement was not observed. At width 20 or 40cm, by increasing the mineral wastewater content, the settlement increases and at the width 30cm, by increasing the mineral wastewater content from 7 to 14%, the settlement reduces and then by increasing the mineral wastewater content up to 21%, the settlement increases. Therefore, the possibility of the creation of the damage to subgrade and the possibility of occurring the rutting failure decreases.

3.7. Response Surface Methodology results

In the following, the recommended function of settlement in terms of two variables width and wastewater content was calculated using Design Expert software and Response Surface method. This function and the 3D plot obtained from this analysis are shown in Table 5 and Fig.16, respectively. According to Fig. 15, some of these values of the settlement are higher than predicted values and some are lower. The recommended function is a quadratic function with regression coefficient of 0.9144 which indicates an acceptable approximation of recommended function.

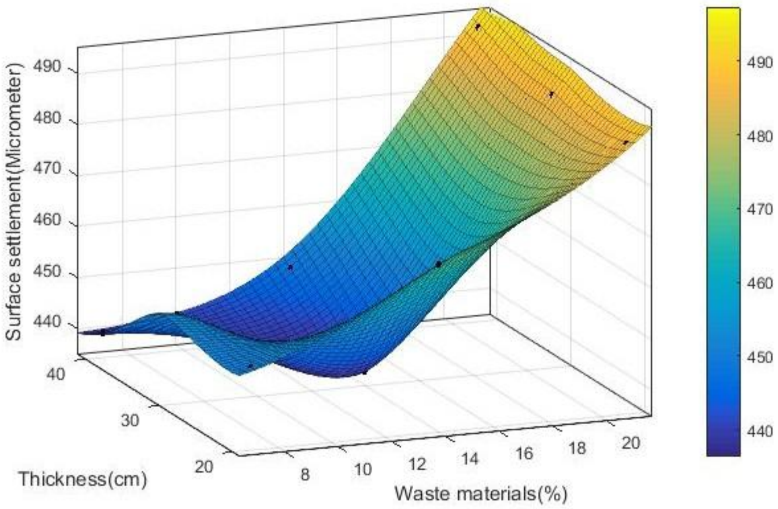


Fig. 15: 3D plot of the settlement obtained in terms of mineral wastewater content and layer width (using MATLAB software)

Table 5: Recommended function from response level method

Variable	Suggested Functions	R-square
Settlement(µm)	$606.98046 - (11.08235 \times \text{Waste materials}) - (6.86730 \times \text{Thickness}) + (0.057143 \times \text{Waste materials} \times \text{Thickness}) + (0.44078 \times \text{Waste materials}^2) + (0.093983 \times \text{Thickness}^2)$	0.9144

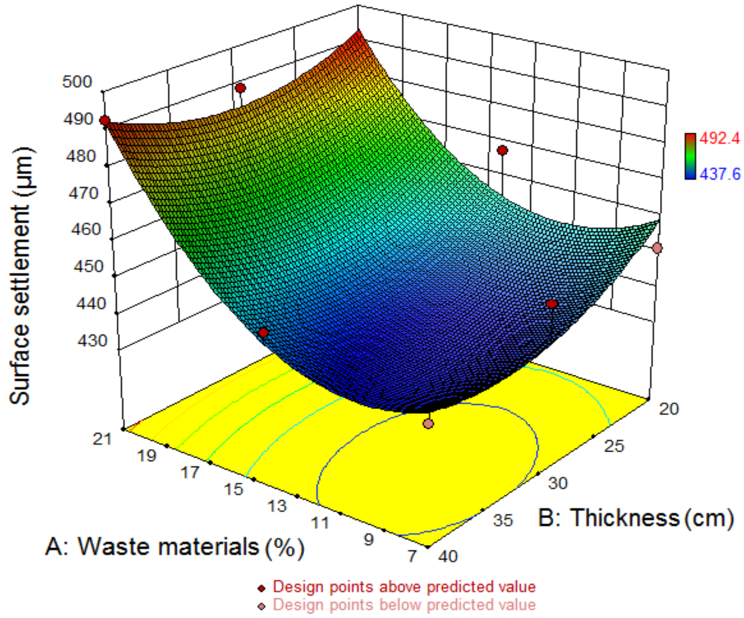


Fig. 16: 3D plot of the settlement based on the results of the Response surface Method using Design Expert software

4. Conclusion

To improve and increase the strength parameters of dune sand, the stabilization with mineral wastewater has been investigated. Mineral wastewater due to the creating environmental issues is hazardous and using these materials in improvement projects with the aim of preventing from entering the environment is of great importance. Compression, direct shear and CBR tests have been investigated at different percentages of the mineral wastewater contents and the results are as follows:

1-Addition of mineral wastewater to the dune sand decreases the optimum moisture and increases the maximum dry density weight. Increasing the mineral wastewater content in soil has increased the maximum dry density weight, but the definite trend was not observed in optimum moisture variations.

2- Addition of mineral wastewater has increased the compressive strength of the soil. Increase in the mineral wastewater content, has decreased the failure cracks.

3-At low normal stresses, addition of mineral wastewater to the dune sand has increased the shear strength in direct shear test, while at high normal stresses, no increase has been observed.

4-Addition of 7% mineral wastewater content to the dune sand has increased about 58% of CBR. Increasing the mineral wastewater content has reduced the CBR, so that at 21 percentage of mineral wastewater content, the lower CBR was observed than that of the non-stabilized soil.

5-Examined SEM images show that addition of mineral wastewater reduces the soil holes and increases the interlocking of the particles. Therefore, increased maximum dry density weight and increased soil strength can be attributed to this factor.

6-The measured settlement in the numerical model in the stabilized layer with 21% of mineral wastewater content is higher than that of the non-stabilized soil. But at 7 and 14 percentages of mineral wastewater in all examined layers, the settlement has reduced compare with non-stabilized soil.

6-By using response level method, settlement function in terms of two variables layer width and the wastewater content was calculated, and the recommended function was a quadratic function with regression coefficient 0.9144.

Commonly, reusing wastewater in construction is considered a deleterious practice since it may introduce pollutants to the environment and generate odor problems. However, this kind of reuse may result in some benefits for pavement subgrade. Currently, the recycle of wastewater in construction and building is seen in some countries as an appropriate environmental policy. In future studies, the environmental benefits and problems of using this or similar material can be examined.

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Numerické a experimentální zkoumání vlivu minerálních odpadních vod a zdokonaleného podloží vozovek z dunového písku

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Abstrakt

V súvislosti s banskou činnosťou je potrebné venovať v súčasnosti špeciálnu pozornosť problémom ochrany životného prostredia. Priemyselné aktivity sa vo všeobecnosti výrazne podieľajú na produkcii nebezpečných emisií a odpadov ako aj na vyčerpávání zdrojov surovín a vody. Jedným zo spôsobov uplatňovania princípov udržateľnosti je využívanie rôznych typov priemyselných odpadov v stavebníctve. Tento príspevok študuje možnosti využitia odpadovej vody a kalu z výroby kovov na stabilizáciu pieskového podložia pri výstavbe cestných komunikácií v Iráne. Pri príprave kompaktných vzoriek bol odpadový kal pridávaný v pomeroch 0, 7, 14 a 21 % k hmotnosti pôvodného pieskového materiálu. Výsledky testovania mechanických parametrov (pevnostných parametrov, skúška zhutnenia, CBR test) poukazujú na zlepšenie sledovaných vlastností vzoriek. U všetkých študovaných vzoriek bolo pozorované zvýšenie pevnosti v tlaku. Najvyšší nárast pevnosti v tlaku (o 44%) bol pozorovaný u vzorky s pridaním 21 % kalu. Pomocou SEM analýzy povrchu vzoriek bol pozorovaný kompaktnejší povrch a pokles pórovitosti u analyzovaných vzoriek. Príspevok prezentuje aj výsledky modelovania hrúbky vrstvy v softvéri EverStress. Výsledky testovania vzoriek s kalom z odpadových vôd poukazujú na možnosť aplikácie takýchto odpadov v cestnom staviteľstve.

Klúčová slova: *Minerální odpadní vody, stabilizace podloží, pevnost ve smyku, pevnost v tlaku, dunový písek.*

Využití odpadního mramorového kalu jako zdroje vápníku pro samohojivé betony s využitím bioremediace

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Souhrn

Předložený článek je zaměřený na využití recyklovaných materiálů ve stavebnictví při návrhu nové směsi cementové pasty s bio-remediačními účinky. V rámci příspěvku je představena metoda bio-remediace betonu, resp. cementové matrice, z pohledu dodatečné aplikace bakterií a živin na povrch porušeného vzorku. Specifikována je problematika z pohledu aplikace v České republice, výběr nejvhodnější bakterie a živin, problematika monitoringu bio-remediace pomocí elektronové mikroskopie a využití mikromletého odpadního mramoru jako zdroje vápníku při remediačních procesech. Výsledky ukazují, že mikromletý mramor pozitivně ovlivňuje bio-remediaci cementové matrice.

Klíčová slova: *Cementový kompozit, odpadní mramorový kal, mikroskopie, recyklace, bio-remediace.*

Úvod

V současné době jsou hledány způsoby, jak co nejvíce prodloužit životnost stavebních konstrukcí. Nejběžněji používaným stavebním materiálem jsou kompozity na bázi cementu, resp. betony. V průběhu životního cyklu betonu může docházet ke vzniku trhlin vlivem smrštění, dotvarování nebo mechanického namáhání[1]. Vzniklé trhliny negativně ovlivňují celkovou životnost betonů. Jednou z možností, jak tento problém eliminovat, je využití efektu samohojení betonu formou zacelování trhlin. Tím je zabráněno pronikání vody do betonových konstrukcí, následnému poškození a destrukci[2]. K samohojení betonu může dojít pomocí samovolné remediace (spontánní kalcinace) nebo bio-remediace (bakteriemi indukované samohojení). Samovolná remediace vytváří krystaly kalcitu precipatací uhličitanu vápenatého ($CaCO_3$). Proces je způsoben reakcí portlanditu s rozpuštěným CO_2 v roztoku, takže celá reakce je závislá na koncentraci volného Ca^{2+} a dostupnosti CO_2, tyto podmínky nelze ovlivňovat, protože se jedná o vnější podmínky[3].

Účinnějším způsobem samohojení betonu je bio-remediace, která je založena na principu bakteriálně indukovaném zacelování trhlin pomocí tvorby nových kalcitových zrn, která se tvoří okolo membrány bakterií. Vytvořené novotvary následně slouží jako krystalizační jádra pro zvětšování krystalů kalcitu. Současné „řešené výzvy“ tohoto typu samohojení jsou především ve způsobu, jak se bakterie aplikují do betonu při samotné výrobě nebo dodatečné nanášení na povrch poškozeného betonu. Klíčové je, aby bakterie bezpečně přežily hydratační a krystalizační procesy spojené s tuhnutím a tvrdnutím cementu, nebo vystavení exteriérovým vlivům počasí. Dalším úkolem je „dodání“ vhodného zdroje živin a vápníku, aby měly bakterie dostatečný zdroj živin a přitom tyto přidané látky neměnily fyzikálně mechanické parametry původního materiálu[4, 5].

Nejčastěji používané bakterie spojené s tímto fenoménem jsou *Sporosarcina pasteurii*, *Bacillus cohnii* a *Bacillus pseudofirmus*. Bio-remediace je založena na vyvolané reakci mezi atmosférickým oxidem uhličitým a vápenatými ionty, rovnice 1 a 2.

$$H_2O + CO_2 \rightarrow HCO_3^- + H^+ \quad (1)$$

$$Ca^{2+} + 2HCO_3^- \rightarrow CaCO_3 + H^+ + HCO_3^- \rightarrow CaCO_3 + H_2O + CO_2 \quad (2)$$

Další možností je využití hydrolýzy močoviny, která je katalyzována bakteriální ureázou (enzymy). Výsledkem této reakce je rozpad močoviny na uhličitan a amoniak, což vede ke zvýšení pH a vyšší koncentraci CO_2 v materiálu, viz rovnice 3 a 4. Močovina, kterou bakterie s ureázou využívá k tvorbě CO_2, ale je degradačním činidlem pro cementové kompozity[6].

$$CO(NH_2)_2 + 2H_2O \rightarrow 2NH_4^+ + CO_3^{2-} \quad (3)$$

$$CO_3^{2-} + Ca^{2+} \rightarrow CaCO_3 \quad (4)$$

Pro tuto experimentální studii byl tedy vybrán mikroorganismus *Bacillus pseudofirmus* z důvodu nepřítomnosti ureázy. Rod bakterií *Bacillus* je odolný vůči prostředí s pH vyšší než 9 a teplotně tolerantní, což je jeho velká výhoda pro využití v podmínkách České republiky[7].

Mikroorganismus *Bacillus pseudofirmus* je fakultativně anaerobní grampozitivní bakterie, která je alkalifilní a alkali tolerantní, a proto je schopna žít a množit se i za vysokého pH (tedy např. i v roztoku vody uvnitř nového betonu). Uvedené vlastnosti se využívají v bio-remediaci betonu. Další výhodou této bakterie je její schopnost tvořit spory, které následně dokáží přežívat „pasivně" i několik let v materiálu a při vhodných podmínkách (teplota, vlhkost a živiny) začít „pracovat". Optimální teplota růstu této bakterie je kolem 30 °C, ale dokáže žít a efektivně se množit v rozmezí od 10 do 40 °C[8]. V rámci svého metabolismu dokáže indukovat reakci vzdušného CO_2 a iontů Ca^{2+}, viz rovnice 1 a 2.

V procesu remediace hraje významnou roli vápník, resp. jeho zdroj, který je zásadním faktorem v celém procesu, a to ať se týká procesu bio-remediace nebo autonomní (samovolné) remediace[9]. Zdroje vápníku jsou různé povahy a v betonové směsi, resp. cementové matrici, mají různou funkci. Ideální je spojit „funkci" v remediačním procesu s nějakou užitečnou funkční ve směsi. Pro takovéto účely je např. možné využít odpadní mramorový kal, který má při nízkém obsahu (do 10 hm. %) plastifikační účinek na směs a pozitivně ovlivňuje i výsledné mechanické vlastnosti betonu[10]. Zároveň může tvořit zdroj vápníku pro oba typy remediace. Článek navazuje na publikované výsledky v časopise WASTE FORUM 2/2018, kde pozitivní vlivy mramorové moučky byly řešeny[11].

Materiály a vzorky

Pro pilotní testování byly použity dva roky staré cementové pasty, abychom eliminovali další vlivy, resp. proměnné, v provedených experimentech. Pro výrobu první sady vzorků byl použit standardní cement CEM I 42,5R (Radotín), vzorky z něho vyrobené byly označené A až C a byly použity jako referenční, srovnávací bez přidaného vápníku. Druhá sada vzorků byla vyrobena s 10% hm. náhradou cementu ve formě mikromleté odpadní mramorové moučky (Beroun, Jež, s.r.o.) a jsou označené D a E (tabulka 1). V obou případech byl použit stejný vodní součinitel 0,35.

Odpadní mramorová moučka z procesu broušení a řezání mramoru sloužila jako další zdroj vápníku pro remediační procesy. Mramorová moučka obsahovala velké shluky zrn a dosahovala zrnitosti od 0 do 90 mikronů, s velikostí středního zrna 29 mikronů a měrným povrchem 177 m^2/kg. Pro zvýšení její aktivity byla mramorová moučka mleta za využití vysokorychlostního mletí ve společnosti Lavaris, s.r.o. (Libčice nad Labem), což mělo za následek zvýšení měrného povrchu. Výsledná mikromletá mramorová moučka dosahovala zrnitosti od 0 do 40 mikronů, s velikostí středního zrna 4,5 mikronů a měrným povrchem 455 m^2/kg. Chemické složení použitých materiálů, zjištěné pomocí XRF analýzy, je v tabulce 2. Při použití Bogueho kalkulace slínkových minerálů, výsledky ukazují, že se jedná spíše o allitický cement s vysokým obsahem C_3S (74,6 hm. %) a nižším obsahem C_2S (7,2 hm. %), C_3A (8,1 hm. %), C_4AF (8,5 hm. %) a MgO (1,6 hm. %). Dále výsledky ukazují na vysokou čistotu odpadního mramorového kalu, kde majoritním prvkem je vápník.

Z cementových past byly vytvořeny mikroskopické leštěné nábrusy, kde do povrchu vzorků byly skalpelem vyryty rýhy, které „simulovaly" trhliny vzniklé na povrchu betonu, průměrná šířka trhliny byla 0,05 mm a hloubka 0,18 mm. Uvedená velikost trhlin je dostačující pro remediaci a současně je možné její zacelení, neboť šířka trhliny tuto skutečnost negativně ovlivňuje[12]. Následně byla na povrch vzorků aplikována směs pro remediaci (voda, živiny a bakterie) v objemu 50 µl, která je popsaná v tabulce 1. Následně byly vzorky umístěny do exsikátoru s vlhkostí blízkou 98 %, která byla vytvořena nasyceným roztokem $CaCl_2$. Na povrch vzorků byla v průběhu experimentu opětovně aplikována směs pro remediaci, a to jedenkrát během prvních 14 dní po třech dnech a následně jednou za 14 dní, vždy tak, aby nedošlo k vyschnutí povrchu vzorku. Vyhodnocení experimentu bylo provedeno ve chvíli, kdy došlo k zacelení trhliny u jednoho z testovaných materiálů, tj. po 2 měsících od aplikace média a bakterií.

V rámci experimentů bylo snahou od sebe oddělit oba typy remediačních procesů (efekt samovolného zacelování trhlin a zacelování indukovaného bakteriemi), které probíhají současně. Byly vybrány základní kombinace vody, živného média, bakterie a mikromletého mramoru, aby bylo možné od sebe oddělit samovolnou remediaci, bio-remediaci a vliv přídavku mikromletého mramoru (viz tabulka 1).

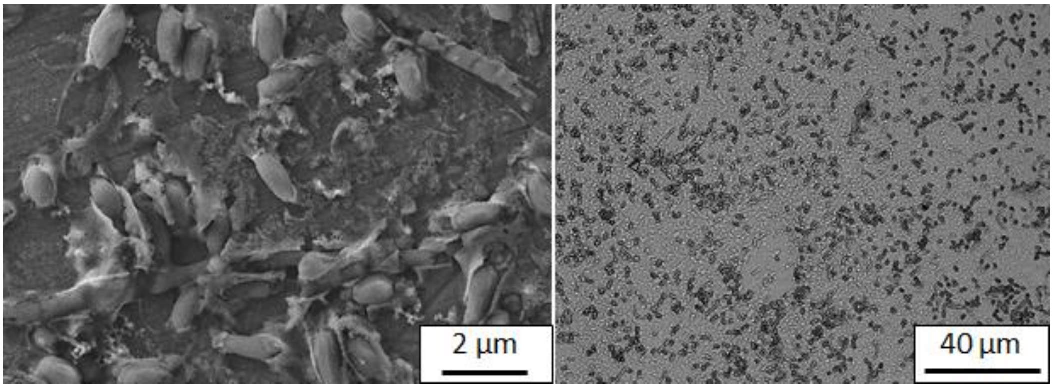
Pro potřeby experimentu byla vybrána bakterie *Bacillus pseudofirmus*. Jako zdroj živin bylo použito živné médium 253 (1 g/L jehněčí-hovězí extrakt; 2 g/L kvasničný extrakt; 5 g/L pepton; 10 g/L NaCl; pH upraveno na 10 pomocí uhličitanové pufru (0,42 g/L $NaHCO_3$; 0,53 g/L Na_2CO_3). Na obrázku 1 jsou snímky z elektronové a optické mikroskopie pro bakterie *Bacillus pseudofirmus*, resp. pro jejich spory.

Tabulka 1: Označení vzorků a složení aplikační směsi na povrch vzorků

Ozn.	**Složení: cement/mramor [g/g]**	**Bakterie**	**Prostředí pro růst bakterií**
A	100/0	Ne	Sterilizovaná voda
B	100/0	Ne	Živné médium 253
C	100/0	Ano	Živné médium 253, bakterie
D	90/10	Ne	Živné médium 253, $CaCO_3$
E	90/10	Ano	Živné médium 253, bakterie, $CaCO_3$

Tabulka 2: Chemické složení portlandského cementu a odpadní mramorové moučky

Chemické složení [hm. %]	**CEM I 42,5R**	**Mramorová moučka**
CaO	64,8	57,5
SiO_2	20,1	5,02
Fe_2O_3	2,51	1,22
Na_2O	0,13	0,73
MgO	1,92	0,39
Al_2O_3	4,02	0,14
SO_3	3,01	0,06
Ostatní prvky	0,45	0,14
Ztráta žíháním	3,05	34,8



Obrázek 1: Bakterie – spory, snímek z elektronové mikroskopie – vlevo, snímek z optické mikroskopie – vpravo

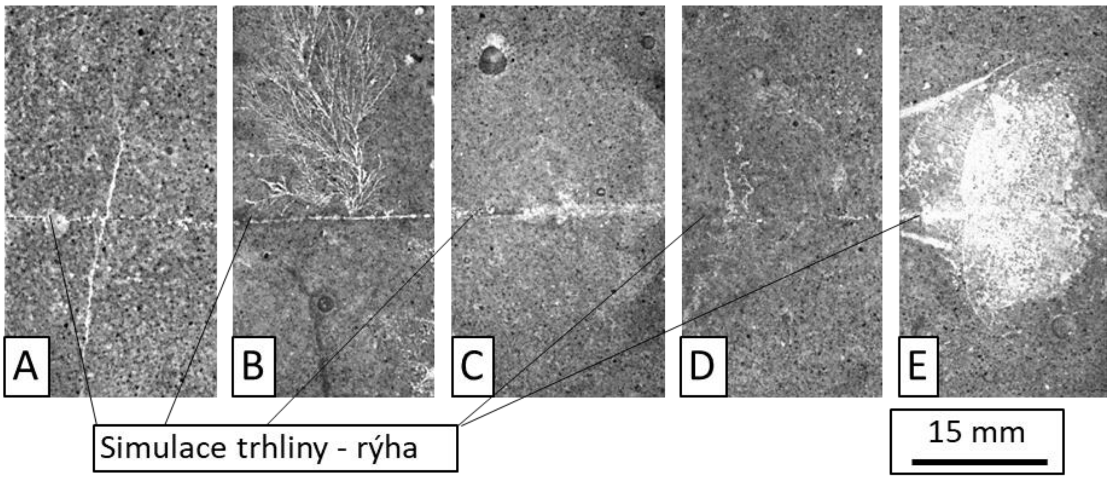
Experimentální metody

Použitými experimentálními metodami byla optická a elektronová mikroskopie (SEM). Pro zjištění poměru zacelení simulovaných trhlin byla použita optická mikroskopie a elektronová mikroskopie byla využita pro popis vzniklých struktur a jejich chemického složení.

Optická mikroskopie byla provedena za použití mikroskopu s transfokátorem a možností 3D zobrazení. Jedná se o přístroj od firmy ZEISS Axio Zoom.V16. Pro elektronovou mikroskopii byl použit rastrovací elektronový mikroskop se Schottkyho katodou FEG SEM Merlin ZEISS, který je umístěn v Laboratoři elektronové mikroskopie a mikroanalýzy na Univerzitním centru energeticky efektivních budov v Buštěhradu. Kvantitativní a kvalitativní analýza chemického složení vzorků byla provedena pomocí rentgenové mikroanalýzy, a to přímo energiově-disperzním spektrometrem (EDS) od firmy Oxford Instruments. V průběhu obrazové analýzy bylo nastavení mikroskopu následující: urychlovací napětí 2 kV, proud 0,2 nA, vzdálenost pracovního stolku 5,5 mm a rozlišení 1024 px. V průběhu prvkové analýzy bylo nastavení mikroskopu následující: urychlovací napětí 20 kV, proud 2 nA, vzdálenost pracovního stolku 8,5 mm a akviziční čas 60 s. Z důvodu vyššího elektrického proudu potřebného pro prvkovou analýzu byly vzorky nejdříve povrchově poprášeny 3 nm vrstvou platiny a až posléze byla provedena prvková analýza.

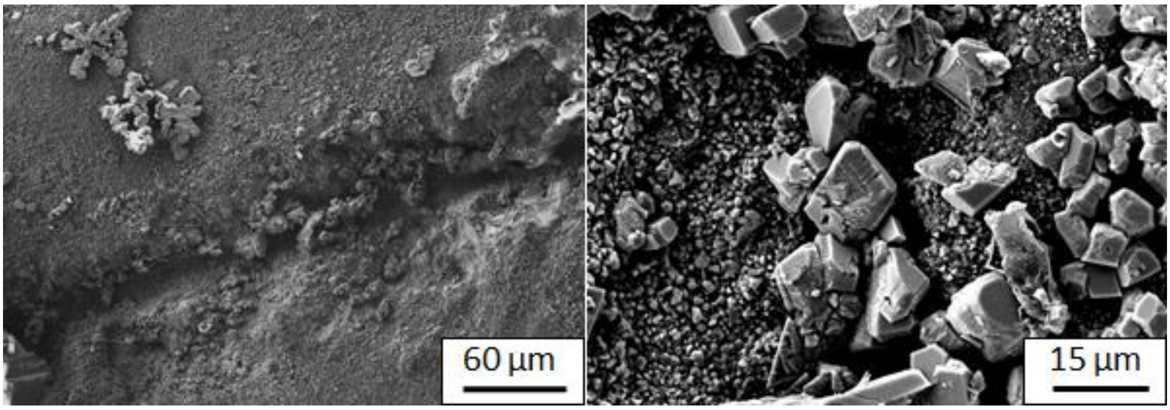
Výsledky a diskuse

Pomocí optické mikroskopie byly vzorky průběžně snímány a v okamžiku, kdy pohledově byla u jednoho ze vzorků trhlina zacelena, byl experiment ukončen. Na obrázku 2 lze vidět poměry zacelení jednotlivých simulovaných trhlin z optického mikroskopu po 56 dnech od „aplikace bakterií“, kdy byl experiment ukončen. Ze snímků z optického mikroskopu lze vidět zacelení trhliny, u vzorků C a E, kde u vzorku E došlo k jejímu celkovému zacelení.



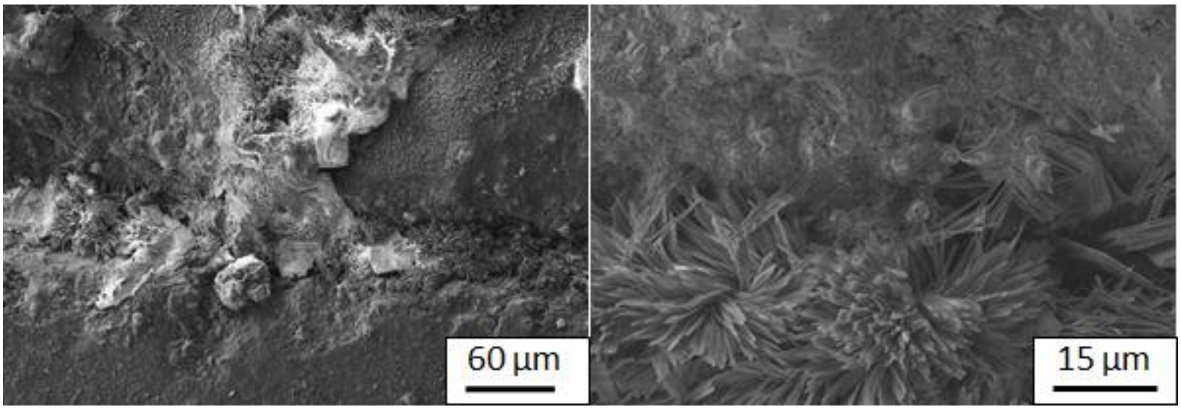
Obrázek 2: Snímky povrchů vzorků cementových past s rýhou, optická mikroskopie (označení podle tabulky 1).

Další výsledky z elektronové mikroskopie jsou prezentovány na obrázcích 3 až 7. V případě aplikace pouze vody na vzorcích A (obrázek 2 a 3), je z makroskopického hlediska vidět, že trhlina není zacelena. Ze SEM analýzy jsou patrná zrna kalcitu s kubickou krystalovou mřížkou, která jsou osamocená a netvoří kompaktnější strukturu, tyto krystaly vznikají jako výsledek samovolné krystalizace uhličitanu vápenatého, který je přítomný v cementové pastě. Uvedený předpoklad potvrdila mikroskopická prvková analýza, protože krystal obsahoval tyto prvky: vápník (34,6 hm. %), uhlík (14,2 hm. %), kyslík (51,1 hm. %) a ostatní prvky (0,1 hm. %). Při přepočtu na atomární procenta a využití stechiometrie, lze konstatovat, že se jedná o $CaCO_3$, tedy kalcit ze samovolného hojení. Velikost krystalu kalcitu byla od 1 do 30 mikronů.



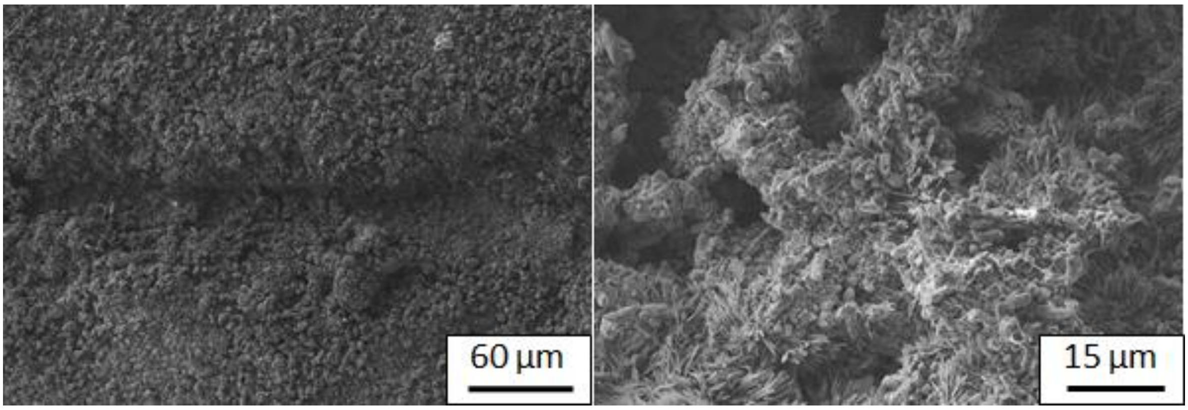
Obrázek 3: Mikroskopické snímky vzorku A, řádkovací elektronová mikroskopie, detektor sekundárních elektronů

Analýza vzorků B, na který byla aplikována směs živin bez bakterií, měla ověřit, jaké útvary se tvoří v trhlině v důsledku aplikace samotného živného média. Na obrázcích 2 a 4 je patrné, že trhlina je částečně zaplněná amorfními útvary. Na SEM fotografiích jsou tyto útvary viditelné jako „lístky" a jedná se o krystalizační struktury proteinů z média[13]. Hypotéza byla potvrzena stanovením chemického složení z těchto míst. Krystalizační struktury měly vysoký obsah sodíku (34,1 hm. %), kyslíku (51,9 hm. %) a uhlíku (11,1 hm. %). Dále zde bylo nalezeno mnoho dalších prvků, jako jsou draslík a vápník (celkově 2,9 hm. %).



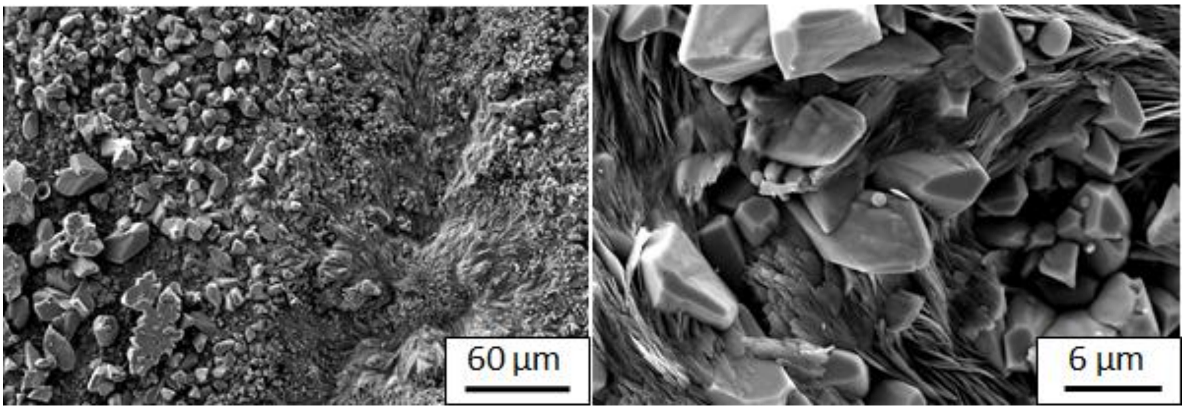
Obrázek 4: Mikroskopické snímky vzorku B, řádkovací elektronová mikroskopie, detektor sekundárních elektronů

Vzorek C s aplikovanou směsí živin a bakterií, viz obrázky 2 a 5, ukazuje „částečně zaplněnou" rýhu a vzniklé novotvary jsou více uspořádány v porovnání se vzorky A a B. SEM snímky ukazují nejen podobné struktury jako na obrázcích 3 a 4, ale také další struktury s amorfní a kubickou strukturou. Jelikož v tomto případě není zajištěn přidaný zdroj vápníku a přítomné ionty vápníku jsou pouze v omezené koncentraci, tak nové amorfní a krystalické struktury jsou pravděpodobně jiné formy $CaCO_3$, tedy kalcitu tvořeného bio-remediací. Chemické složení bylo obdobné jako v případě samovolné remediace, tedy: vápník (41,4 hm. %), kyslík (44,2 hm. %), uhlík (12,2 hm. %) a ostatní prvky (2,2 hm. %). Chemické složení je mírně zkresleno přítomnými krystalizačními strukturami proteinů, které jsou obsaženy i v ostatních prvcích. Oproti kalcitu tvořenému samovolnou remediací má kalcit z bio-remediace menší velikost (menší než 1 mikron).



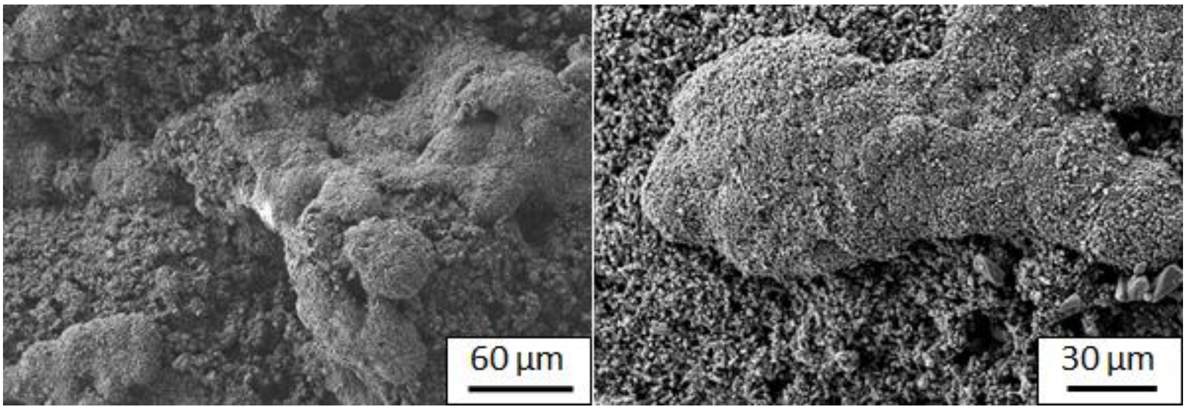
Obrázek 5: Mikroskopické snímky vzorku C, řádkovací elektronová mikroskopie, detektor sekundárních elektronů

V případě vzorku D (obrázky 2 a 6) lze vidět pozitivní efekt přidaného vápníku ve formě odpadní mikromleté mramorové moučky. Simulovaná trhlina a její nejbližší okolí je zaplněno velkým množstvím krystalů ve velikosti od 1 do 30 mikronů. Chemická analýza potvrdila, že se jedná o krystaly $CaCO_3$, tedy kalcitu ze samovolné remediace. Navíc je struktura plná krystalizačních struktur ve formě lístků, tedy zkrystalizovaných proteinů ze živného média.



Obrázek 6: Mikroskopické snímky vzorku D, řádkovací elektronová mikroskopie, detektor sekundárních elektronů

Nejlepší výsledek byl dosažen u vzorku E, tedy vzorku s přidaným vápníkem, živným médiem a bakteriemi. V tomto případě došlo k celkovému zacelení simulované trhliny (obrázek 2) a lze ve struktuře vidět výrazné kopečkovité uskupení krystalů ve velikosti menší než 1 mikron. Podle chemické analýzy se jedná o krystaly $CaCO_3$, tedy kalcit tvořený bio-remediací. Dále lze vidět, že struktura neobsahuje krystalizované proteiny, a tedy bakterie spotřebovaly všechno živné médium na zacelení trhlin (obrázek 7).



Obrázek 7: Mikroskopické snímky vzorku E, řádkovací elektronová mikroskopie, detektor sekundárních elektronů

Popis samovolné tvorby kalcitu a bakteriemi indukované tvorby bylo určeno z experimentu s přídavkem zdroje iontů vápníku, živin a bakterií. V případě směsi bez bakterií je trhlina zaplněna krystalickými útvary a amorfními útvary z živného média. Při použití bakterií ve stejné směsi byla trhlina zacelena z větší části a ze SEM analýzy jsou jasně patrné útvary s krystalickou strukturou, které mají „tvar“ bakterií. Pravděpodobně se jedná o bakterie pokryté různými formami kalcitu a samotná těla bakterií vytvářela nukleační centrum pro růst krystalů. Poměry rozdělení kalcitu vzniklého samovolně a bio-remediací korespondují s výsledky ostatních autorů[14].

Zcela patrný je pozitivní vliv přidaného zdroje vápníku – mikromletého mramoru – na oba typy remediací. V našem případě byl použit odpadní mramorový kal oproti běžně používanému laktátu vápníku (mléčnanu vápenatého), který je přidáván společně s bakteriemi a živným médiem[15].

Závěry

Z výsledků vyplývá, že samovolná tvorba krystalů $CaCO_3$ (na povrchu vzorků nebo v uměle vytvořené rýze) probíhá na vzorcích i bez bakterií, její míra je závislá na množství vápenatých iontů a CO_2, a také na rychlosti tvorby krystalizačních zrn kalcitu. V případě použití bakterií je míra tvorby nového $CaCO_3$ vyšší a je závislá na množství a zdroji Ca^{2+}. Bakterie podporují tvorbu kalcitu, a to nejen svým metabolismem, ale také slouží jako krystalizační jádra pro samovolnou krystalizaci. Obě popsané reakce od sebe nelze jednoznačně oddělit, protože probíhají současně. Kritériem jejich popisu může být kvantitativní porovnání, protože efekt autonomního samohojení je „omezený“. Přidaný zdroj vápníku ve formě odpadní mikromleté mramorové moučky měl pozitivní vliv na zacelení trhlin a v kombinaci se živným médiem 253 a bakterií *Bacillus pseudofirmus* došlo k celkovému zacelení simulované trhliny. U ostatních testovaných vzorků trhlina zcela zacelena nebyla.

Výsledky jasně ukázaly, že při vhodné volbě složení cementové směsi je možné docílit synergického efektu. Vhodně vybraná a upravená přidaná druhotná surovina (v našem případě mramorový kal) může pozitivně ovlivnit nejen výsledné užitné vlastnosti betonu[11], ale prodloužit i jeho životnost formou samohojení. Další fáze výzkumu se bude zabývat aplikací remediační směsi přímo do čerstvé směsi betonu.

Poděkování

Tento příspěvek byl připraven díky podpoře Grantové agentury České republiky (GA ČR) k projektu „Samohojení cementových kompozitů v důsledku bakteriální kalcifikace” č. GA18-15697S a za podpory ČVUT v Praze (SGS) č. SGS19/148/OHK1/3T/11.

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Use of waste marble sludge as a source of calcium for self-healing concrete with the use of bioremediation

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Summary

The presented article is focused on the use of recycled materials in construction in the design of a new mixture of cement paste with bio-remediation effects. The paper presents the method of bio-remediation of concrete, respectively. cement matrix, from the point of view of additional application of bacteria and culture medium to the surface of the damaged sample. The issues from the point of view of application in the Czech Republic, the selection of the most suitable bacteria and culture medium, the issues of monitoring bio-remediation using electron microscopy and the use of micronized waste marble as a source of calcium in remediation processes are specified. The results show that micronized marble has a positive effect on the bioremediation of the cement matrix.

Keywords: Cement composite, waste marble sludge, microscopy, recycling, bio-remediation.

České ekologické manažerské centrum, z.s. a časopis WASTE FORUM
zvou na
Týden výzkumu a inovací pro praxi a životní prostředí (TVIP 2020)
který se koná v náhradním termínu
11. – 13. 11. 2020 *(netypicky středa-pátek)* **v Hustopečích, hotel Amande.**
V rámci TVIP se spolu s konferencí APROCHEM koná tradičně symposium
Výsledky výzkumu a vývoje pro průmyslovou a komunální ekologii
ODPADOVÉ FÓRUM 2020

Symposium je určeno:

- k prezentaci výsledků (především) aplikovaného výzkumu z celé oblasti průmyslové a komunální ekologie,
- pro zástupce podnikatelské sféry a veřejné správy, aby se seznámili s výzkumnými tématy a projekty s cílem eventuálního převzetí nebo rozvinutí dosažených výsledků v praxi,
- k seznámení představitelů výzkumné obce s potřebami reálného „podnikového života“ a případnému navázání spolupráce.

Původně vyhlášený program po vynuceném přesunu termínu konání **zůstává v naprosté většině v platnosti a až do 30. 9. je možné jej doplnit o nově přihlášené příspěvky** (v případě přednášek v omezeném, u vývěsek v téměř neomezeném rozsahu).
Původní přihlášky k účasti automaticky zůstávají v platnosti (pokud ji účastník sám svou účast nezruší), **nově se k účasti lze přihlásit do 1. 11. 2020**.

K tradičním problémovým okruhům:

Odpady:
- Systémové otázky odpadového hospodářství
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- Nebezpečné odpady, odstraňování odpadů
- Sanace ekologických zátěží a následků havárií

Voda:
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- Získávání cenných látek z odpadních vod
- Recyklace vody
- Nakládání s kaly, kapalné odpady

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- Doprava a lokální zdroje
- Kvalita ovzduší a zdravotní rizika

Věda a výzkum pro oběhové hospodářství:
- Šance a bariéry cirkulární ekonomiky
- Nové zdroje surovin a energie
- Inovativní technologické postupy a inovativní technologie
- Nové materiály a jejich aplikace (bio- a nanomateriály)

je letos po dvou letech ve spolupráci s Centrem výzkumu Řež opět zařazeno téma **Radioaktivní odpady**.

INFORMACE PRO AUTORY

Přihlášky příspěvků lze zasílat do naplnění kapacity – přihlašovací formulář naleznete ZDE**.** Úspěšné odeslání přihlášky je automaticky potvrzeno. Zhruba měsíc před konáním konference bude na www.tvip.cz zveřejněn aktualizovaný program. Autoři příspěvků budou požádáni, aby zkontrolovali správnost informací uvedených v programu.

Abstrakta (souhrn) přednášek – stručný souhrn obsahu přednášky i vývěsky je nedílnou součástí přihlášky příspěvků, rozsah textu max. 500 znaků (včetně mezer). Abstrakt bude zahrnut do tištěného programu konference.

Plné texty přednášek – autory všech příspěvků, **tj. přednášek i vývěsek**, žádáme o včasné předání graficky upraveného plného textu příspěvku v **elektronické podobě** (MS Word) **nejpozději do 15. 10. 2020**. Po tomto termínu nemůžeme garantovat jejich zařazení do sborníku na CD-ROM, který obdrží účastníci konference při registraci.

Grafická úprava textu - příspěvky před zařazením do sborníku konference neprocházejí redakční a ani grafickou úpravou, při jejich psaní můžete s výhodou využít šablonu, kterou spolu s detailním popisem formátování najdete na www.tvip.cz v sekci Informace pro autory.

Prezentace – je nutné předat přítomné obsluze nejpozději 5 minut před začátkem sekce, do které je zařazena přednáška. Pokud prezentaci obdržíme do 15. 10. 2020, bude rovněž zařazena do sborníku na CD-ROM.

Pro vlastní prezentaci přednášky mají přednášející (pokud není uvedeno jinak) k dispozici **15 minut a 5 minut je vyhrazeno pro diskusi**. Ve spolupráci s předsedajícími sekcí se budeme snažit o maximální dodržování vyhlášeného časového rozvrhu.

Přednáškové místnosti budou vybaveny **dataprojektory**, včetně **notebooků**. Použití vlastního notebooku je možné, funkčnost propojení je třeba na místě předem ověřit ve spolupráci s technikem a současně je nezbytné poskytnout prezentaci obsluze pro další zpracování na DVD.

Vývěsky – formátu **A0** (na výšku) budou přichyceny lepicí páskou na tvrdý podklad (sklo, dřevěné obklady). Vystaveny budou po celou dobu konference v chodbě před hlavním sálem nebo přímo v sále. V programu bude vymezen časový prostor („Autorská prezentace vývěsek“), kdy by autoři měli být přítomni u své vývěsky.

Účast autorů: Autoři se rovněž přihlašují k účasti, na konferenci musí být přihlášen a **osobně přítomen alespoň jeden z autorů** příspěvku, anebo jím pověřená osoba. Jednacím jazykem je **čeština** a **slovenština**. **Zahraniční hosté** jsou srdečně zváni, tlumočení však organizátor nezajišťuje, prezentace příspěvků v angličtině je možná. **Za neodpřednášenou přednášku nebo nevystavený poster bude dodatečně autorovi fakturován poplatek 1000 Kč** (bez DPH) za zařazení příspěvku do programu a jeho uveřejnění ve sborníku.

Recenze: Organizátor konference nemá námitek, aby autoři nabídli svůj příspěvek z konference k uveřejnění v některém recenzovaném časopise, včetně časopisu WASTE FORUM, který je indexován v databázi **SCOPUS**.

Komerční přednášky či krátká sdělení jsou za úplatu možné. Rozsah možností firemní prezentace je široký, stejně jako cenové rozpětí *(více* ***ZDE****)*. Rozhodně není možné komerční sdělení prezentovat jako odbornou přednášku či vývěsku. V případě porušení této zásady bude dodatečně fakturována příslušná částka podle výše zmíněného ceníku.

INFORMACE PRO ÚČASTNÍKY

Hotel Amande, kde se TVIP 2020 koná, se nalézá na adrese Husova 8, Hustopeče.
Vložné na **TVIP** zahrnuje vstup na obě akce (APROCHEM i ODPADOVÉ FÓRUM), brožuru s programem a souhrny všech příspěvků a CD-ROM či flashdisk s plnými texty příspěvků a předem včas dodanými prezentacemi. Vybírat je možné ze tří typů vložného:
Plné vložné (4 450 Kč bez DPH)
Dvoudenní vložné (3 950 Kč bez DPH)
Jednodenní vložné (3 450 Kč bez DPH)
Přihlášky účasti je možné zasílat **do 1. 11. 2020** (dále možné po dohodě s pořadatelem) prostřednictvím připraveného internetového formuláře. V přihlášce specifikujte také veškeré požadavky na stravu a ubytování.
Ubytování a stravování zajišťuje pořadatel. Vzhledem k omezené ubytovací kapacitě **hotelu Amande Hustopeče** nabízíme ubytování také v těsně sousedícím **hotelu Rustikal a v Penzionu pod Radnicí**. Ubytování je možné v jednolůžkových anebo dvojlůžkových pokojích. V případě dvojlůžkového pokoje je nutné v přihlášce účasti specifikovat jméno spolubydlícího.
Stravování během konference pro ty, kteří je mají objednáno, je zajištěno v hotelu Amande, výjimkou jsou snídaně, ty má každý účastník v tom hotelu, kde je ubytován.
Podrobnější informace, včetně cen ubytování a stravování najdete na www.tvip.cz v sekci Informace pro účastníky.

Open Innovation Matchmaking in Ecology (Waste Management)

Cílem symposia je mj. napomoci setkávání a propojování účastníků za účelem navazování nových příležitostí ke spolupráci. Abychom tento aspekt podpořili, připravili jsme **ve spolupráci s WASTen, z.s.,** tzv. **„Open Innovation Matchmaking in Ecology (Waste Management)“**. Každý, kdo bude mít zájem o asistované propojení s jiným účastníkem, může tak učinit předem prostřednictvím připraveného formuláře nebo na místě na registraci TVIP.

Exkurze

Exkurze proběhnou ve čtvrtek **12. listopadu** mezi cca **14,00 – 17,30 hod**. Pro rok 2020 se připravují následující exkurze:

- **HANTÁLY, a.s.** - prohlídka skládky, kompostárny a dotřiďovací linky plastů,
- **Vetropack Moravia Glass, a.s.** - odborný výklad s prohlídkou závodu předního výrobce obalového skla v Evropě.

Exkurze včetně dopravy na místo jsou zdarma. **Zájem o účast je nutné uvést v přihlášce účasti nebo dodatečně emailem na cemc@cemc.cz.**

DŮLEŽITÉ TERMÍNY na závěr:
Termín konání: 11. – 13. 11. 2020, z toho
Odpadové fórum: 11. – 13. 11. 2020
Aprochem: 12. – 13. 11. 2020
Přihlášky příspěvků**: 30. 9. 2020** (dále po dohodě s pořadateli)
Zaslání plných textů: 15. 10. 2020
Přihlášky účasti**: 1. 11. 2020**