GEOTECHNICAL STUDY OF A NEW HETEROPHASIC MATERIAL BASED OF MUNICIPAL SOLID WASTE INCINERATOR BOTTOM ASH

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Abstract: This presented work investigates the valorization of the Municipal Solid Waste Incinerator Bottom Ash in Civil Engineering. The bottom ash from waste incineration consists of, by their origin, a typical granular materials. They are industrial by-products resulting from the incineration of the domestic wastes; and the way of considered valorization is road gravel. In this paper, the geotechnical characteristics of bottom ash taken from a recycling company in the North of France has been presented. The results help to classify our bottom ash according to the technical guide of realization of embankments and subgrades and compare with other bottom ash in the litterature.

Keywords: Bottom ash; geotechnical characteristic; incineration; road gravel.

1. Introduction

Municipal solid wastes can be treated by various ways, including landfilling, recycling/recovery and incineration for energy. In many countries, municipal solid waste incineration (MSWI) for energy recovery represents the most common waste management technologies [20], [23]. The dramatically reducing of mass and volume of the solid wastes due to the incineration leads to the decreasing of the requirements for landfilling [3], [17, [18], [19], [23]. However, there is still a considerable amount of solid incineration residues which are generated after the combustion, among that bottom ash is the highest, about 80% [5], [23], [26].

In the past, MSWI bottom ash was mostly treated by sanitary landfilling. The possibilities other than landfilling have been investigated, and reutilization of incinerator bottom ash was already considered many years ago. In Civil Engineering, the road field consumes a significant quantity of aggregates [1], [27], [28]. However, the aggregate reserves are increasingly not exploitable for various reasons: inaccessible, integrated into an urban area, in classified or protected sites, too expensive exploitation and risks of environmental impact. In this context, the valorization of the bottom ash in road field is an interesting alternative.

Since bottom ash is a granular inert and compactable material, bottom ash is mainly used in Civil Engineering for constructing embankments, road layers, and parking areas, etc [1], [14], [22]. In France, about 3 million tons of bottom ash is produced annually [2]. The use of bottom ash began in Paris in the late 1950s. The expansion of its use throughout the country occurred in the late 1980s - 1990s [4].

This article presents firstly the geotechnical characteristics concerning the sector of valorization of road works controlled by particle size distribution, methylene blue value, sand equivalent, Los Angeles and Micro-Deval (with the presence of water)

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coefficients, natural moisture content, absolute density, Proctor compaction and bearing capacity index IPI tests. On the other hand, the comparison this bottom ash with other ones is carried out.

2. Material

The MSWI bottom ash used in this study originated from the Platform of recycling of the PréFerNord Company located in Fretin, France. PréFerNord recovers “slag” resulting from the combustion of 5 incineration plants.

To calibrate the materials, a pre-treatment of this bottom ash like sifting, removal of ferrous and not - ferrous elements, was carried out on site. After, this bottom ash was matured for 3 months (Figure 1). A range of particle sizes from 0 to 20 mm was chosen to approach the size range of natural aggregates which is usually used in the road field.

Figure 1 : *Bottom ash*

3. Geotechnical characteristics

3.1. Particle size distribution

The particle size distribution [11] obtained by sieving three samples that were taken by quartering and washingat 80 μm of diameter shows that bottom ash fits in the spindle of the road gravel (Figure 1).

The results of the particle size distribution presented in Figure 1 show that the bottom ash is characterized by various or spread out size distribution (coefficient of uniformity C_u = 35,5) along with the too many coarse elements which generate much vacuum (coefficient of curvature C_c = 2,3).

With: Coefficient of uniformity $C_u = \frac{D_{60}}{D_{10}}$ (1)

Coefficient of curvature $C_c = \frac{{D_{30}}^2}{D_{10} * D_{60}}$ (2)

D_x is the diameter of particles for x % of cumulative passing ones.

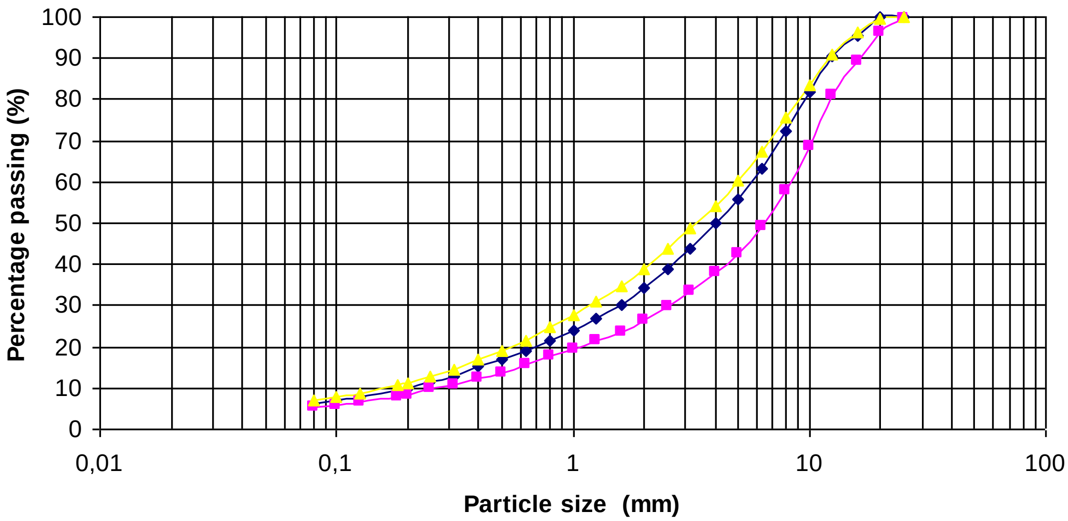

Figure 2: *Particle size distributionby sieving*

The Table 1 represents the useful parameters for the classification of our bottom ash.

Table 1 : *Particle sizenecessary for classification*

D_{max}	20 mm
Passing to 80 µm	6.3 %
Passing to 2 mm	33.2 %

3.2. Methylene blue values

Themethylene blue test [13] measures the capacity of fine elements to absorb methyleneblue. The methylene blue is preferentially adsorbed by the clays, the organic matter, and the iron hydroxides; this capacity globally reports the surface activate of these elements. "Methylene blue value" of fine elements is defined as the quantity expressed in grams of methylene blue adsorbed per 100 grams of fine elements.

From 0-5 mm granularity sample, the test consists of measuring the quantity of methylene blue which can adsorb itself on the material sample in suspension.The methylene blue values (MBV) determined in three testsare presented in Table 2. The average methylene blue value less than 0.1 indicates that bottom ash is similar to sandy soil and therefore, insensitive to water [22].

Table 2: *Methylene blue values*

	Sample 1	**Sample 2**	**Sample 3**	**Average**
MBV	0.05	0.06	0.06	0.057

3.3. Sand equivalent

The sand equivalent [12], making it possible to measure the cleanliness of sand, is performed on 0-5 mm granularity sample.It gives globally the quantity of the fine elements, by expressing a volumetric conventional ratio between the sedimented sandy elements and the flocculated fine elements.The value of the sand equivalent is the ratio, multiplied by 100, between the height of thesedimented sandy part, and the total height of flocculated and sedimented sandy parts.

The obtained equivalent sand values Es and the visual equivalents sand values E_{sv} for bottom ash are presented in Table 3. These high values (> 85) show that bottom ash can be considered as a very clean sand owing to the absence of fine clay [16]. These results join the results of the particle size distribution and the methylene blue tests, namely the small proportion of fines of bottom ash.

Table 3: *Sand equivalent values*

	Sample 1	Sample 2	Sample 3	Average
Es	168	153.9	167	163
Esv	105	97.4	96.4	99.6

3.4. Los Angeles

Los Angeles test [6] measures the resistance to fragmentation by the impact of the constituents of a sample aggregates. It consists of measuring the number of elements less than 1.6 mm produced by shocking the material to the normalized balls in the machine Los Angeles.

Measurements were performed on 10-14 mm and 6.3-10 mm granularity samples. The obtained results are shown in Table 4.

Table 4: *Los Angeles tests values*

Fraction	Sample 1	Sample 2	Sample 3	Average
10/14 mm	39	42	41	40.7
6.3/10 mm	35	38	45	39.3

The higher the value, the higher the material breaks under the shock. The threshold being 45, this granulate can be used as a layer in the same state with or without a hydraulic binder [22].

3.5. Micro-Deval (with presence of water)

This test [7] measures the usury (attrition) of the constituents of a sample aggregates. It consists of measuring the usury of the aggregates produced by mutual friction in a rotating cylinder.

In this case, the test was designed with the presence of water. Measurements were performed on 10-14 mm and 6.3-10 mm granularity samples. The obtained results are shown in Table 5.

Table 5: *Micro-Deval tests values*

Fraction	Sample 1	Sample 2	Sample 3	Average
10/14 mm	20	19	18	19
6.3/10 mm	24	23	24	23.7

Thus, the threshold being 45, this granulate can be used in subgrade and foundation layer is in the same state with or without a hydraulic binder [22].

3.6. Moisture content

The moisture content defines the water status of the material. It is equal to the ratio of the mass of water contained in the sample and the dry mass of the sample and expressed in %.

Samples were taken and dried in a stove for three days at a temperature of 105 ^oC. The main cause of this high moisture content (Table 6) is the influence of rain before samples are taken from storage.

Table 6: *Moisture content values*

	Wet mass (g)	Dry mass (g)	Moisture content (%)
Sample 1	643	542	18.6
Sample 2	697	602	15.8
Sample 3	810	675	20
Average			18.1

3.7. Absolue density

The absolute density [8] of bottom ash was determined by using a helium pycnometer of type AccuPyc 1330. This test is to measure the volume of solid grains from the change of helium pressure by applying the perfect gas law: PV = nRT. By knowing the mass of the sample, the absolute density is determined by the ratio between the mass of the solid grain and volume.

The measurement was made on the crushed and dried bottom ash. The value obtained is about 2.70 t/m^3 (Table 7). This value is similar to that of quartz-based sand.

Table 7: *Absolute density*

	Sample 1	Sample 2	Sample 3	Average
Absolute density (g/cm^3)	2.70	2.70	2.69	2.70

3.8. Proctor compaction

The compaction is the densification of the soil by applying the mechanical energy to improve the engineering properties of soils. It contributes in particular to translate or eliminate compaction risk, increase the resistance of soil and slope stability, improve the bearing capacity of road, limit unwanted volume changes, for example, by the action of frost, swelling or shrinkage.

The compaction capacity of the material is assessed through the Normal Proctor and the Modified Proctor tests [9]. Both trials are identical in principle, apart from the difference of the parameters defining applied compaction energy.The principle of the test is to compact the material at different moisture contents and in process energy. For each moisture content, wet and dry masses are determined. And, compaction characteristics (dry density and optimum moisture content) are determined.

Figure 3 shows the Normal Proctor and Modified Proctor compaction curves. Table8 shows the obtained characteristics with Optimal Normal Proctor (OPN) and Optimal Modified Proctor (OPM). Based on the results, bottom ash may be considered as a highly compactable material, which is desirable to prevent future settlements and to inscrease strength and stability of the layer.

Table 8*: Compaction characteristics*

	OPN	OPM
Optimal moisture content (%)	15.0	12.5
Optimal dry density (g/cm^3)	1.78	1.87

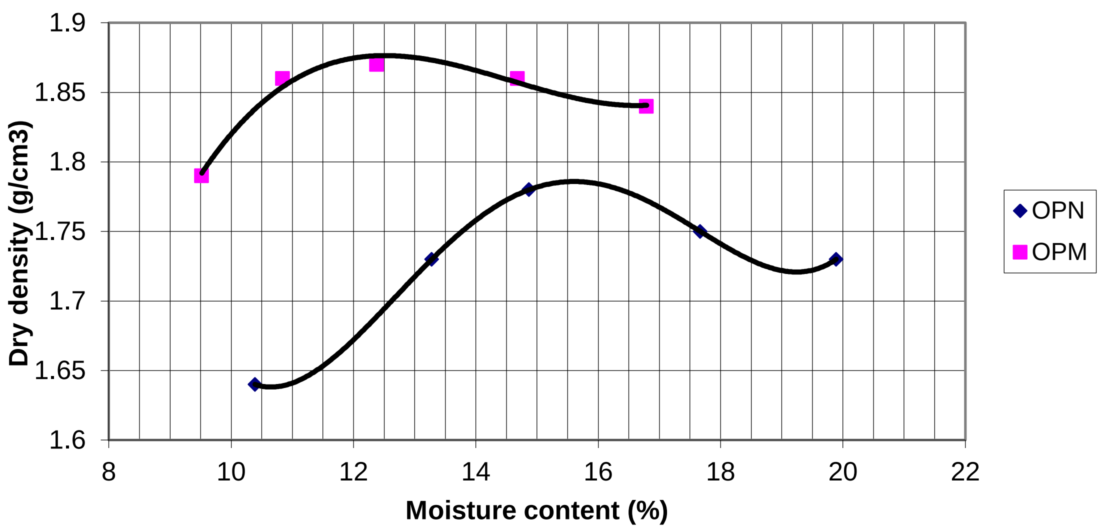

Figure 3 : *Normal Proctor compaction curves*

3.9. Bearing Capacity Index

The Bearing Capacity Index [10] is the quantity used to assess the capacity of a material to bear directly on its surface the movement of construction equipment. In conjunction with testing Modified Proctor, punching action on compacted specimens are performed to estimate the Bearing Capacity Index.

Figure 4 shows the variation of the Bearing Capacity Index with the moisture contents. According to the recommendations of the French standard [15], to ensure the normal circulation of the machines on a construction site, the desirable values of the Bearing Capacity Index at least 45 for the base layers and 35 for foundation layers. However, this standard also defines the minimum values that must not be less than 35 base layers and 25 for the foundation layers. With Bearing Capacity Index of 70 (Figure 4), bottom ash can be considered stable.

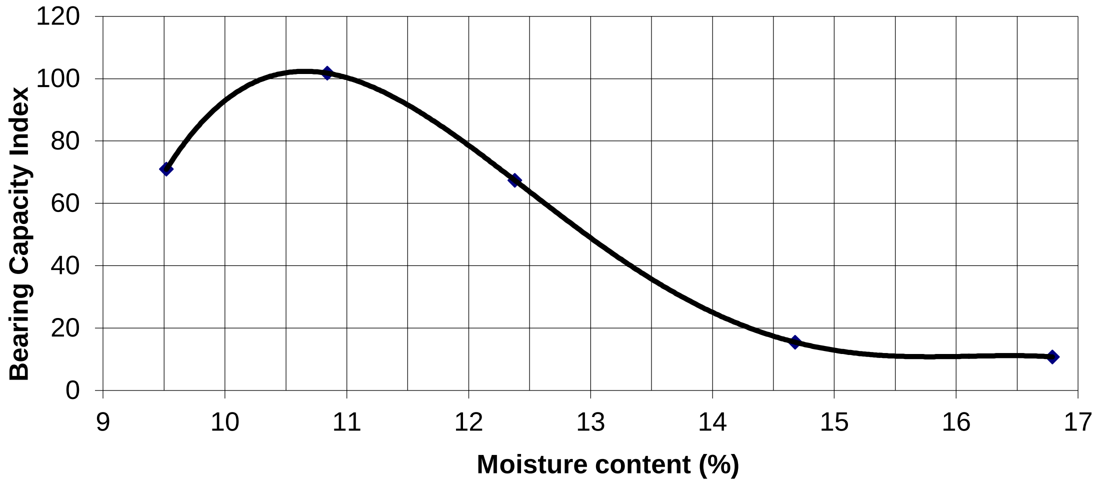

Figure 4: *Bearing Capacity Index curve*

4. Discussions

The geotechnical test is carried out. These tests present natural parameters (particle size distribution, methylene blue, sand equivalent), mechanical parameters (Los Angeles, Micro-Deval) and state parameters (moisture content, absolute density, Proctor compaction, Bearing Capacity Index). Bottom ash has a varied or spread out particle size distribution along with too many coarse elements what generate much vacuum. The tested bottom ash is then a granular material with continued grain size distribution and low proportions of non-plastic fine (< 63µm,) and coarse (> 20mm) fractions. Therefore, this may be easily compacted to obtain a high resistance [24], [25]. Bottom ash could be considered a well-graded material.

The obtained values of MBV and Esv are respectively 0.057 and 99.6. This low value of of MBV reveals the presence of a very low amount of swelling clay. This indicates that bottom ash is similar to sandy soil and thus insensitive to water [22]. The sand equivalent was very high (>85). This result complies with that of the methylene blue value and shows that bottom ash can be considered very clean sand due to the absence of clay fines [22], [24], [25]. It consolidates data from the particle size analysis in Table 1, namely the low proportion of fines. According to the Guide technique SETRA D9233-1 [22], bottom ash can be classified as D2. D2 corresponds to the category alluvial aggregates, own insensitive to water. From the Guide technique SETRA D9233-1 [22], this aggregate can be used in road embankments in the same state with or without a hydraulic binder. The absolute density of bottom ash was around 2.7 g/cm^3. This value classifies bottom ash as an aggregate that is lighter than natural ones like sand and gravel. The density is an added benefit that may reduce settlement in use, due to the lower normal stresses caused by the self-weight [29], [30].

The values of LA and MDE, less than 45, so this granulate can be used in subgrade and foundation layer is in the same state with or without a hydraulic binder.

Obtained values from optimum Proctor and absolute density indicate that il is desirable to prevent future settlements of bottom ash layer. According to the recommendations of the French standard [15], to ensure the normal circulation of the machines on site, the desirable values of Bearing Capacity Index are at least 45 for the base layers and 35 for the foundation layers. However, this standard also defines the minimum values, which must not be less than 35 for the base layers and 25 for the foundation layers. With an Bearing Capacity Index of 70, this material can be considered stable.

Geotechnical tests were performed according to the procedure describes in Table 6. Values of geotechnical tests of bottom ash for technical guide of realization of embankments and subgrades [22] and the French regulation 2012 [21] are also presented in Table 6. So, the geotechnical characteristics of the bottom ash lies well in the litterature an it demonstrate the potential of the use of the material for road construction.

Table 6: *Values of geotechnical tests of bottom ash*

Parameters	Values for the technical guide of realization of embankments and subgrades (SETRA, 2000)	Values for the French regulation 2012 (SETRA, 2012)	Values for the material
Granularity	0/31.5 mm	0/20 or 0/31.5 mm	0/20 mm
Contents of fines	5 % $\leq$ passing to 0.063 mm $\leq$ 12 %	4 % $\leq$ passing to 0.063 mm $\leq$ 12 %	5.7 %
Passing to 2 mm	20 % $\leq$ passing to 2 mm $\leq$ 45 %	20 % $\leq$ passing to 2 mm $\leq$ 50 %	33.2 %
Mythylene blue test on fraction 0/5 mm (MBV)	0.01 <MBV < 0.1	MBV < 0.1	0.057
Sand equivalent (SE)	35 < SE < 70		99.6
Los Angeles (LA)	36 ≤ LA ≤ 50	35 ≤ LA ≤ 45	40.7
Micro-Deval (with the presence of water) (MD)	15 ≤ MD ≤ 45	15 ≤ MD ≤ 40	19
Natural moisture content (W)	8 % ≤ W ≤ 25 %	8 % ≤ W ≤ 20 %	18.1 %
Modified optimum Proctor	Optimum moisture content: 12.5 % ≤ W ≤ 15 % Maximum dry density: 1.75 ≤ ρd (g/cm^{3}) ≤ 1.87	Optimum moisture content: 12.5 % ≤ W ≤ 16 % Maximum dry density: 1.75 ≤ ρd (g/cm^{3}) ≤ 1.87	12.5 % 1.87 g/cm^3
Bearing capacity (IPI)	30 ≤ IPI ≤ 60	40 ≤ IPI ≤ 100	70

5. Conclusions

The geotechnical characteristics show that bottom ash is sandy soil, insensitive to water and has a small proportion of fines. It has a varied or spread out particle size distribution along with too many coarse elements what generate much vacuum. According to SETRA-LCPC, our aggregate can be classified in the category D2. The category D2 corresponding to alluvial gravel is insensitive to water. And this aggregate can be used in road embankments in the same state with or without a hydraulic binder. The absolute density of bottom ash was around 2.7 g/cm^3. This value classifies bottom ash as an aggregate that is lighter than natural ones like sand and gravel. The values of LA and MDE indicatethis granulate can be used in subgrade and foundation layer is in the same state with or without a hydraulic binder. Obtained values from optimum Proctor and absolute density indicate that il is desirable to prevent future settlements of bottom ash layer. With the Bearing Capacity Index value, this material can be considered stable. The geotechnical characteristics of the bottom ash lies well in the litterature an it demonstrate the potential of the use of the material for road construction.

REFERENCES

[1] ADEME BRGM, *Mâchefers d'incinération des ordures ménagères*, État de l'art et perspectives, 2008.

[2] ADEME ITOM, Les installations de traitement des ordures ménagères 2008, 2008.

[3] Arm M., "Variation in deformation properties of processed MSWI bottom ash: results from triaxial tests", *Waste Management* 24, 1035-1042, 2004.

[4] Badreddine R., François D., "Assessment of the PCDD/F fate from MSWI residue used in road construction in France", *Chemosphere* 74, 363-369, 2008.

[5] Chimenos J. M., Segarra M., Fernandez M. A., Espiell F., Characterization of the bottom ash in municipal solid waste incinerator", J*ournal of Hazardous Materials*, Vol 64, 211-222, 1999.

[6] European standard EN 1097-1, *Tests for mechanical and physical properties of aggregates. Determination of the resistance to wear (Micro-Deval),* European committee for standardization, 1996.

[7] European standard EN 1097-2, *Tests for mechanical and physical properties of aggregates. Methods for the determination of resistance to fragmentation,* European committee for standardization, 1998.

[8] European standard EN 1097-7, *Tests for mechanical and physical propertiesof aggregates. Determination of the particle density of filler. Pycnometermethod,* European committee forstandardization, 1999.

[9] European standard EN 13286-2, *Unbound and hydraulically bound mixtures. Test methods for the determination of the laboratory reference density and water content. Proctor compaction,* European committee for standardization, 2005.

[10] European standard EN 13286-47, *Unbound and hydraulically bound mixtures. Test method for the determination of Californian bearing ratio, immediate bearing index and linear swelling*, European committee for standardization, 2003.

[11] European standard EN 933-1, *Tests for geometrical properties of aggregates. Determination of particle size distribution*. Sieving method, European committee for standardization, 1997.

[12] European standard EN 933-8, *Tests for geometrical properties of aggregates. Assessment of fines,* Sand equivalent test, European committee for standardization, 1997.

[13] European standard EN 933-9, *Tests for geometrical properties of aggregates. Assessment of fines,* Methylene blue test, European committee for standardization, 1996.

[14] Forteza R., Far M., Segui C., Cerda V., "Characterization of bottom ash in municipal solid waste incinerators for its use in road base," *Waste Management* 24, 899-909, 2004.

[15] French standard NF P 98-115, *Assises de chaussées. Exécution des corps de chaussées*, 2009.

[16] Izquierdo M., Vazquez E., Querol X., Barra M., Lopez A., Plana F., *Use of bottom ash from municipal solid waste incineration as a road material*, Proceeding of International Ash Utilization Symposium, Center for Applied Energy Research, University of Kentucky, 2001.

[17] Le N. H., Abriak N. E., Benzerzour M., Binetruy C., "Comportement mécanique d'un mâchefer d'incinération d'ordures ménagères", *Journal of catalytic materials and environment* 10, 3-12, 2012.

[18] Le N. H., Abriak N. E., Binetruy C., Benzerzour M., Chaki S., *The study of behavior of bottom ash under homogeneous stresses. Determination of parameters for Nova behavior models,* Proceeding of Euromediterranean Symposium on Advances in Geomaterials and Structures, Djerba, Tunisia, 653-660, 2010.

[19] Le N. H., Abriak N. E., Binetruy C., Benzerzour M., Shahrour I., Rivard P., "Finite Element Modeling of the Mechanical Behavior of Municipal Solid Waste Incineration Bottom Ash with the Mohr-Coulomb Model", *International Journal of Environmental, Chemical, Ecological, Geological and Geophysical Engineering*, Vol 9 No 12, 1373-1380, 2015.

[20] Lin C. L., Weng M. C., Chang C. H., "Effect of incinerator bottom ash composition on the mechanical behavior of backfill material", *Journal of Environmental Management*, Vol 113, 377-382, 2012.

[21] SETRA, *Guide technique. Acceptabilité environnementale de matériaux alternatifs en technique routière*, *Les mâchefers d'incinération de déchets non dangereux (MIDND),* 2012.

[22] SETRA-LCPC, *Guide technique SETRA D9233-1. Réalisation des remblais et des couches de forme*, Fascicule I, 2000.

[23] Zekkos D., Kabalan M., Syal S. M., Hambright M., Sahadewa A., "Geotechnical characterization of a municipal solid waste incineration ash from a Michigan monofill", *Waste Management* 33, 1442-1450, 2013.

[24] Izquierdo M., Lopez A., Vazquez E., Barra M., Querol X., "Characterisation of bottom ash from municipal solid waste incineration in Catalonia", *Journal of Chemical Technology and Biotechnology* 77, 576-583, 2002.

[25] Izquierdo M., Vazquez E., Querol X., Barra M., Lopez A., Plana F., *Use of bottom ash from municipal solid waste incineration as a road material*, Proceeding of International Ash Utilization Symposium, Center for Applied Energy Research, University of Kentucky, 2001.

[26] Tang P., Florea M. V. A., Spiesz P., Brouwers H. J. H., "Characteristics and application potential of municipal solid waste incineration (MSWI) bottom ashes from two waste-to-energy plants", *Construction and Building Materials* 83, 77-94, 2015.

[27] Kim B., Prezzi M., Salgado R., "Geotechnical properties of fly and bottom ash mixtures for use in highway embankments", *Journal of Geotechnical and Geoenvironmental Engineering* 131, 914-924, 2005.

[28] Sormunen L. A., Kolisoja P., "Mechanical properties of recovered municipal solid waste incineration bottom ash: the influence of ageing and changes in moisture content", *Road Materials and Pavement Design* 19, 252-270, 2016.

[29] Lynn C. J., Ghataora G. S., Dhir R. K., "Municipal incinerated bottom ash (MIBA) characteristics and potential for use in road pavements", *International Journal of Pavement Research and Technology* 10, 185-201, 2016.

[30] Muhunthan B., Taha R., Said J., "Geotechnical engineering properties of incinerator ash mixes", *Journal of the Air and Waste Management Association* 54, 985-991, 2004.

TÓM TẮT

NGHIÊN CỨU ĐẶC TÍNH KỸ THUẬT CỦA VẬT LIỆU XỈ TRO MỚI DỰA TRÊN XỈ TRO ĐỐT CỦA CHẤT THẢI RẮN ĐÔ THỊ

Bài báo trình bày về kết quả nghiên cứu về việc sử dụng chất thải rắn đô thị dưới đáy lò đốt trong xây dựng dân dụng và công nghiệp. Xỉ tro đốt của chất thải rắn đô thị (hay còn gọi là tro đáy) là sản phẩm phụ của quá trình đốt cháy chất thải đô thị ở nhà máy xử lý chất thải. Việc nghiên cứu sử dụng tro đáy là rất cần thiết, góp phần giảm thiểu tác động của môi trường và giải phóng không gian chôn lấp. Trong bài báo này, các đặc tính kỹ thuật của tro đáy đã được nghiên cứu, phân tích, từ đó đánh giá khả năng sử dụng tro đáy trong vật liệu xây dựng dân dụng và công nghiệp.

Keyword: Tro đáy; chất thải rắn đô thị; xỉ tro.