International Journal of GEOMATE, April., 2021, Vol.20, Issue 80, pp.152-158
ISSN: 2186-2982 (P), 2186-2990 (O), Japan, DOI: https://doi.org/10.21660/2021.80.j2066
Geotechnique, Construction Materials and Environment

STATIC AND CYCLIC PROPERTIES OF MUNICIPAL SOLID BOTTOM ASH IN VIETNAM

*Nguyen Chau Lan[1], Nguyen Hai Ha[2], Nguyen Anh Tuan[3], Vu Anh Tuan[4], *Ngo Huy Dong[5]

[1,2,3]Faculty of Civil Engineering, University of Transport and Comunications, Viet Nam
[4]Le Quy Don Technical University, Viet Nam[5,*]Fecon Corporation, Viet Nam

*Corresponding Author, Received: 02 Dec. 2020, Revised: 11 Jan. 2021, Accepted: 06 Feb. 2021

ABSTRACT: In this study, direct shear tests and cyclic triaxial tests were conducted to investigate the effectiveness of using municipal solid waste bottom ash (MSWIBA) material as fill material or base/sub-base in Vietnam. A square of large – scale (300 x 300 x 140 mm) and a small scale (60 mm in diameter) direct shear test were carried out on MSWIBA samples to study the effect of specimen size on shear strength of the samples. The results show that the MSWIBA sample at R95 has a very high CBR value of 115%, which is much higher than the CBR value of crushed stone for subgrade applications. The cohesion and friction angle in the case of R95 are higher than those in the case of R90. The value of cohesion and friction angle in the large direct shear test are significantly higher than those obtained in the small direct shear test. The shear strength of MSWIBA is like natural sand. The resilient modulus decreased with the increase of deviator stress in the case of R90 sample and increased with the increase of deviator stress in the case of R95. The numerical method results also show that MSWIBA material can be used as construction material such as roadbed and foundation layers.

Keywords: MSWIBA, large direct shear test, cyclic triaxial test, resilient modulus.

1. INTRODUCTION

The amount of municipal solid waste (MSW) is increased significantly due to the rapid development of industrialization, urbanization, and population of society. Annual production rates of 1840 million tons of MSW have been reported worldwide. A huge amount of 6400 tons is generated daily in Hanoi, Vietnam. MSW management has become the most important issue in sustainable development in developing countries.

Recently, the incineration method is applied for MSW treatment in Vietnam. Incineration is the process of control and complete combustion of solid wastes. The temperature in incinerators varies between 980-2000 °C. One of the most attractive features of incineration is a reduction in the volume of combustible solid waste by 80-90%. Unfortunately, in Vietnam, the application of incineration for MSW treatment is still limited compared to the other methods such as composting, landfill, and recycling. Several incinerators have been installed in Hanoi and a large amount of MSW incinerator bottom ash (MSWIBA) will be generated.

The mechanical properties of MSWIBA was investigated by several researchers [1-5]. It showed that MSWIBA can be utilized for road embankment such as fill material for base/sub-base layer. The stiffness, compressibility and friction angle of treated MSWIBA was studied by using unconfined compression test and static triaxial test [6]. It is noted that the mechanical properties of MSWIBA were similar to dense sand. The internal friction angle of MSWIBA was from 38°–55° [1]. However, the effect of specimen size on the shear strength of the samples has not been investigated yet. On the other hand, the research on the cyclic behavior of MSWIBA for road construction material is still limited

In this paper, direct shear tests, and cyclic triaxial tests are conducted to investigate the effectiveness of using MSWIBA material as fill material or base/sub-base in Vietnam. A square of large – scale (300 x 300 x 140 mm) and a small scale (60 mm in diameter) direct shear test were carried out on MSWIBA samples to study the effect of specimen size on shear strength of the samples. The flexible pavement was modeled by using the finite element method (PLAXIS 3D) in the case of using soil and MSWIBA material for the sub-base layer. The outcomes of this research will facilitate the selection of MSWIBA for road construction material.

2. MATERIALS AND METHODS

2.1 Materials

The MSWIBA samples were obtained from the Thanh Quang incinerator in Hanoi capital. Approximately 200 kg of the wet waste samples were collected and then dried in a room with an average temperature of 20 ^{o}C. The water content of MSWIBA was 25% and the specific gravity of the waste sample was 2.635. The particle size distribution of samples for small and large direct shear tests determined according to ASTM D422 is shown in Figure 1. It is noted that the maximum diameter of MSWIBA for the small and large direct shear test was 4.75 mm and 40 mm, respectively. The uniformity coefficient, C_u ($C_u = D_{60}/D_{10}$) of the small sample and large sample were 8.16 and 3.24, respectively.

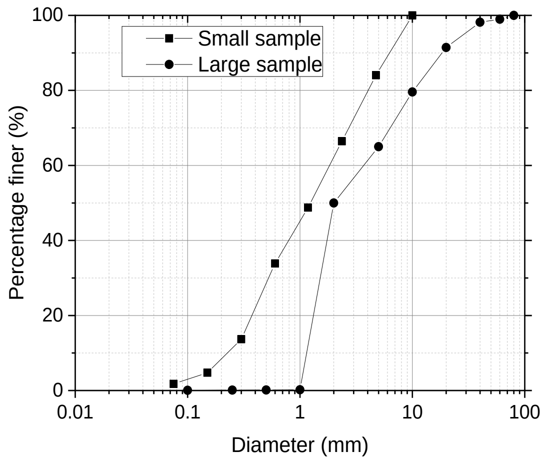

Fig.1 Gradation curve of MSWIBA for small and large direct shear tests

2.2 Methods

2.2.1 XRD and SEM tests

The X-ray diffraction (XRD) and Scanning Election Microscopy (SEM) analysis was conducted for the MSWIBA sample according to ASTM D5758 standard. The XRD test results of MSWIBA samples are plotted in Figure 2. The X-ray diffraction analysis results show that the sample is composed of Quartz mineral (Silicon dioxide SiO_2) and Calcium Carbonate ($CaCO_3$) (Figure 2). The SEM and EDS results of the sample are presented in Figure 3 and Figure 4. It is observed that the MSWIBA has irregular shape particles with a rough surface. This similar behavior was also noticed in the previous research reported by [1-3]. Figure 4 shows that the main components of the MSWIBA sample are Ca, Si, and O.

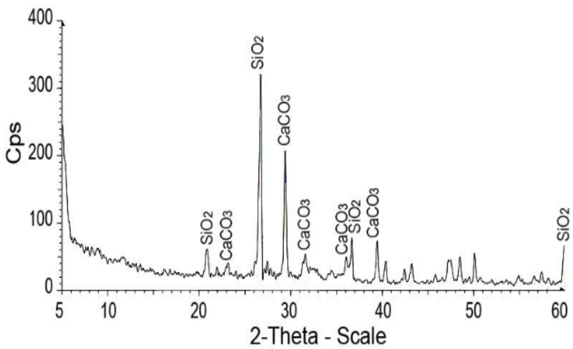

Fig.2 XRD result for MSWIBA sample

2.2.2 Compaction test

After physical tests, several mechanical tests such as compaction test and direct shear test were conducted according to ASTM D698 standard and ASTM D3080 standard, respectively (Table1). The Standard Proctor Compaction test was conducted for a large sample of MSWIBA. Both types of samples used for small and large direct shear tests were prepared by compacting to the compaction ratio, which was reached 90 % and 95 % of maximum dry density (R90, R95). The compaction ratio is defined as the ratio between dry density in the field and maximum dry density which were conducted by using laboratory standard proctor test (ASTM D698).

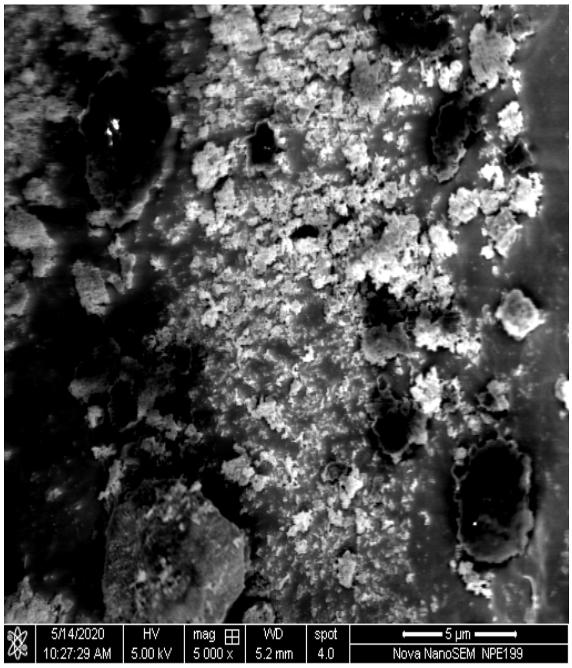

Fig.3 SEM result for MSWIBA sample

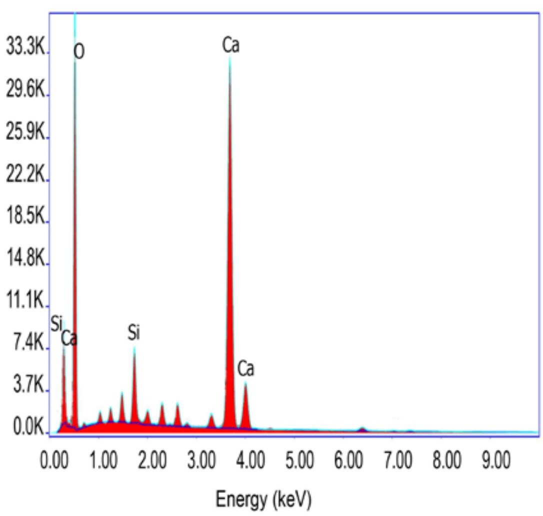

Fig.4 EDS result for MSWIBA sample

Table 1 Summary of the test

Type of test	Name of test	Standard
Physical test	Moisture content determination	ASTM D2216
	Grain size analysis	ASTM D422
	Compaction	ASTM D698
Mechanical tests	CBR	ASTM D1883
	Direct shear test	ASTM D3080
Cyclic test	Cyclic triaxial test	AASHTO T307-99
Microstructure test	X-ray diffraction analysis (XRD)	ASTM D5578
	Scanning Election Microscopy (SEM)	

2.2.3 California Bearing ratio (CBR)

CBR test was conducted following ASTM D1883. The MSWIBA sample passing the 4.75 - mm sieve was compacted at optimum water content and 95 % of maximum dry unit weight in a 6 inch mold with standard proctor effort. The specimen was then cured in a 100% relative humidity room for 7 days and was immersed in water and allowed to soak for 4 days. After soaking, the free water was drained and CBR test was performed. The CBR value of MSWIBA is shown in Table 2 and compared with typical CBR values of different soil types.

Table 2 shows that the MSWIBA sample at compaction ratio of R95 has a very high CBR value of 115%, which is much higher than the CBR value of crushed stone for subgrade applications. The higher CBR value shows the higher strength of material, which can support the pavement load.

Table 2 CBR of MSWIBA and CBR of soils for subgrade applications

Material	CBR (%)	Rating
MSWIBA sample		
MSWIBA (R95)	115	Very good
Soil for Subgrade Applications		
Crushed stone	30-80	Very good
Gravel	30-80	Very good
Silty gravel	20-60	Very good
Sand	10-40	Fair good
Silty sand	5-30	Fair good
Silty	1-15	Poor-fair
Clay	1-15	Very poor

2.2.4 Small and large direct shear test

For the direct shear test, small samples of 60 mm in diameter were conducted with normal vertical stress of 50 kPa, 100 kPa, and 150 kPa. For the large direct shear test, specimens were prepared by a modified compaction test in the large direct shear box (300 mm × 300 mm × 140 mm). The large direct shear test was performed on an WYKEHAM FARRANCE direct shear-testing machine with the maximum shear force of 100 kN. In this test, D/d_{max}= 300/40= 7.5 (where D is the width of the shear box in the large direct shear test and d_{max} is the maximum particle size of MSWIBA). For simulating the specimen overburdened at different depths, normal stresses were adopted of 100 kPa, 200 kPa, and 300 kPa. Horizontal shear was then applied at a speed of 1.2 mm/min.

Table 3 Detail of cyclic triaxial testing sequence for the experimental soils

No.	Confining Pressure, σ_3 kPa	Max. Axial Stress, σ_{max} kPa	Number of load cycles (cycle)
1	41.4	13.8	1000
2	41.4	27.6	100
3	41.4	41.4	100
4	41.4	55.2	100
5	41.4	68.9	100
6	27.6	13.8	100
7	27.6	27.6	100
8	27.6	41.4	100
9	27.6	55.2	100
10	27.6	68.9	100
11	13.8	13.8	100
12	13.8	27.6	100
13	13.8	41.4	100
14	13.8	55.2	100
15	13.8	68.9	100

2.2.5 Cyclic triaxial test

To use MSWIBA as a subgrade soil or untreated base/sub-base materials, resilient modulus (Mr) test was conducted by using a cyclic triaxial machine. Basically, the system consists of a computer-controlled loading frame that can provide a cyclic loading on a soil sample mounted inside a triaxial cell. The cyclic triaxial test procedures were followed the testing standard AASHTO T307-99

(2007) "Standard method of test for determining the resilient modulus of soils and aggregate materials".

The triaxial specimens of 70 mm in diameter and 100 mm in height were prepared by using the compaction method. The sample was prepared at optimum moisture content and dry unit weight, which was obtained by compaction test. The haversine-shaped load form was used and a cyclic load duration of 0.1 seconds followed by a recovery duration of 0.9 seconds was applied. The details of the loading sequences and the number of cycles are shown in Table 3.

2.3 Numerical simulation

In this study, the flexible pavement system is modeled by using the finite element method (FEM), 3D PLAXIS software. The pavement structure consists of asphalt concrete surface layer, asphalt concrete base layer, granular subbase layer, and subgrade layer. The thickness of the surface layer, base layer, subbase, and sub-grade layer are 5 cm, 10 cm, 30 cm, and 40cm, respectively. The sub-base layer is modeled in case of using soil and MSWIBA material. The cross-section of the selected pavement structure presented is shown in Figure 5. The material and constitutive models in case of without MSWIBA materials are shown in Table 4. It is noted that the resilient modulus of the subbase layer is about 60 MPa based on Falling Weight Deflectometer (FWD) measurement at the site.

In case of using MSWIBA material, the modulus of the sub-base layer is replaced by the resilient modulus, which is obtained from the cyclic triaxial test. The resilient modulus for the sub-base layer was 110 MPa. The static loading is applied for pavement structures with a pressure of 600 kPa.

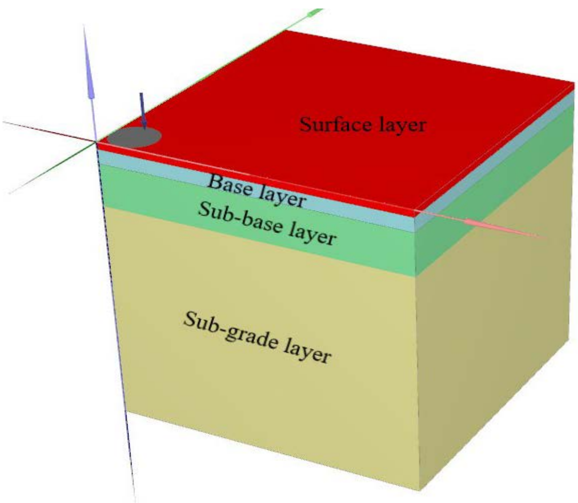

Fig.5 FE axisymmetric model for pavement structure

Table 4 Model parameters

	Surface layer	AC base	Subbase		Subgrade
Model			Mohr-Coulomb		
	Linear Elastic	Linear Elastic	Subbase	MSWI BA	Mohr-Coulomb
Thickness (m)	0.05	0.10	0.3	0.3	1.05
Young's modulus (MPa)	4000	3000	60	110	40
Poisson' ratio	0.35	0.35	0.45	0.45	0.45
Dry density (kN/m^3)	23	23	20	12.6	17
Saturated density (kN/m^3)	-	-	22	16	20
Cohesion (kN/m^2)	-	-	10	3.7	0
Friction angle	-	-	30	42	35
Dilatation angle	-	-	15	17	5

3. RESULTS AND DISCUSSION

3.1 Results of soil samples

3.1.1 Compaction test result

The compaction result for the small sample and the large sample is presented in Figure 6. It shows that the maximum dry unit weights for the small sample and large samples are 12.6 kN/m^3 and 15.2 kN/m^3, respectively. The optimum water content of the small sample and large sample are 25.2% and 22.5 %, respectively. Large samples showed higher maximum dry unit weight and lower optimum water content because of the size and the modified compaction effort. This would be due to the irregular rough surface texture in MSWIBA.

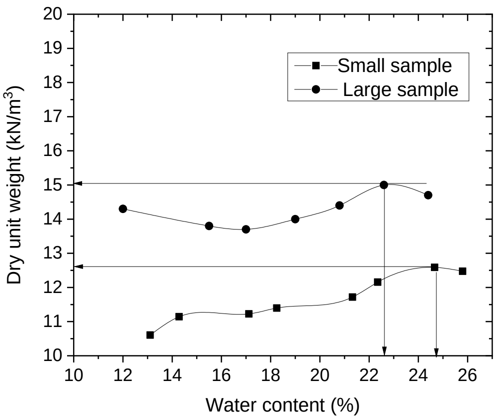

Fig. 6 Compaction result for the small sample and large sample.

3.1.2 Direct shear test results

The shear strength parameters for small direct shear tests and large direct shear tests in two cases with a compaction ratio of R90 and R95 are summarized and compared with the previous research in Table 5. It is noted that the cohesion and friction angle in case of R95 are higher than that in the case of R90. It is explained that the sample compacted to reach the higher of density (R95) is denser than that of R90 samples. So the R95 sample has higher strength than R90 sample. The results from small direct shear test of R90 was found similar to the values obtained from the direct shear test reported by [4]. The value of cohesion and friction angle in the large direct shear test are significantly higher than that obtained in small direct shear test. In both of large and small direct shear test, the values of friction angle in case of R95 are higher than those in case of R90 due to the higher density of the sample. It is also reported that shear strength of MSWIBA similar to natural sand. In addition, MSWIBA is lighter than sand that may reduce the settlement of embankment when using MSWIBA for fill material. It is recommended that the MSWIBA can be used as material for backfill in case of compaction ratio of R90 and R95.

Table 5 Comparison of shear strength parameters with other research

Type of test	Cohesion, (kPa)	Friction angle (degree)	Reference	
CD triaxial test	-	53°-59°	[6]	
	Range 14-34	24°-50°	[7]	
CD and CU triaxial test	1	55°-59° (CD) 53°-56° (CD)	[6]	
Direct shear test (small sample)	0	38°-55°, mean 45°	[8]	
	--	44°-53°	[9]	
	8	50°	[10]	
Direct shear test (This study)	1.2	40°	R90	Small direct shear test (60 mm indiameter)
	3.7	42°	R95	
	73	31°	R90	large direct shear test (300mm x300mm)
	79	44°	R95	

3.1.3 Cyclic triaxial test results

The resilient modulus of MSWIBA at R90 and R95 tested under different confining pressures of 41.4 kPa, 27.6 kPa, and 13.8 kPa are shown in Figure 7 and Figure 8. It is noted that the highest values were obtained for both samples at the beginning of the cyclic load triaxial test (Figure 7, Figure 8). In the case of the R90 sample, the Mr value decreased to some extent before it fluctuated and finally reduced when the deviator stress increased up to 70 kPa. Similar behavior was found for MSIWBA for the base layer, reported by [11]. It is explained that this behavior is related to the different chemical reactions such as CHS and CAH which has taken place during the MSWIBA aging [12].

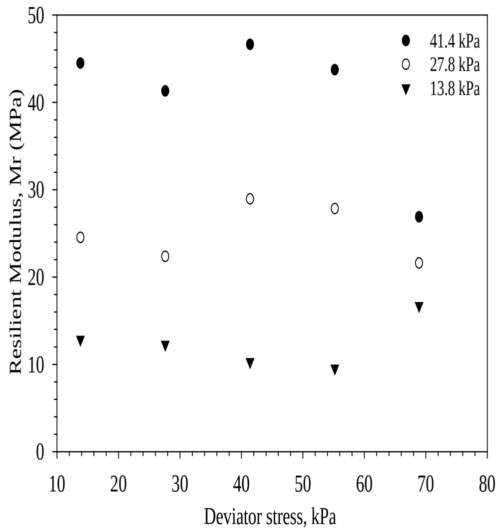

Fig.7 Resilient modulus for MSWIBA sample at R90

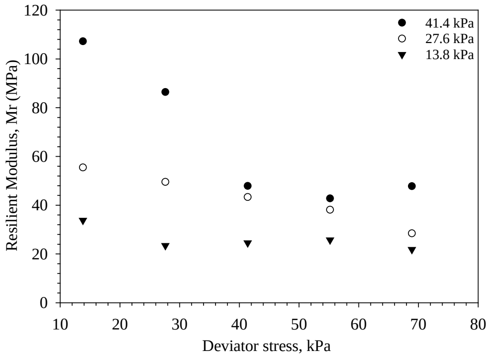

Fig.8 Resilient modulus for MSWIBA sample at R95

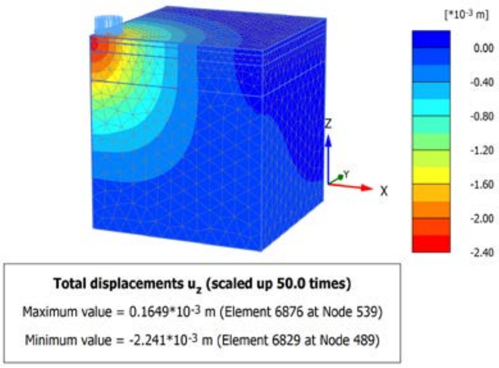

Fig. 9 Vertical displacement profile for pavement structure (Using soil material, Mr=60 MPa).

On the other hand, the behavior of the R95 sample is different from that of the R90 sample because the particle size of these two samples are different. The resilient modulus increase with the increase of confining pressure and decreases with the increase of deviator stress. The highest value of resilient modulus (Mr) is approximate 110 MPa for cell pressure of 41.4 kPa while the lowest value of Mr is 20 MPa for cell pressure of 13.8 kPa. Similar behavior was found for coarse-grain size material for sub-base material, reported by [13].

3.2 FEM results

Figure 9 and Figure 10 show the vertical displacement profile for pavement structure. It can be seen that the vertical displacement decreases with the increase of resilient modulus of subbase layer. The maximum vertical displacement is 2.28×10^{-3} m in case of using soil material for sub-base layer, while it is 2.165×10^{-3} m in case of using MSWIBA material with the resilient modus of 110 kPa for sub-base layer. It is evident that the MSWIBA material can be used as material for pavement design [14].

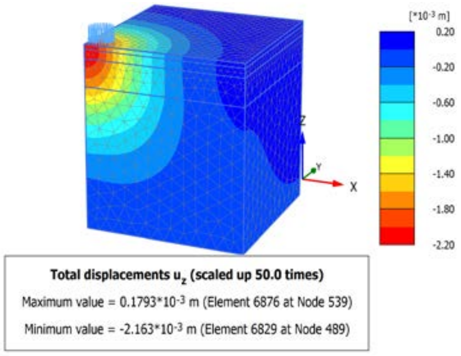

Fig. 10 Vertical displacement profile for pavement structure (MSWI BA, Mr=110 MPa)

4. CONCLUSIONS

Based on the experimental and finite element results, the following conclusion can be drawn as follows:

- The specimen size of sample has significant effect on the shear strength of the samples. The large samples showed higher maximum dry unit weight and lower optimum water content because of the size and the modified compaction effort.
- The MSWIBA sample at R95 has very high CBR value of 115%, which is much higher than the CBR value of crushed stone for subgrade applications.
- The cohesion and friction angle in the case of R95 are higher than those in the case of R90 due to the higher density of the sample. The value of cohesion and friction angle in large direct shear test are significantly higher than those obtained in small direct shear test.
- In the case of R90 sample, the Mr value decreased to some extent before it fluctuated and finally reduced when the deviator stress increased up to 70 kPa.
- In the case of R95 sample, the resilient modulus increase with the increase of confining pressure and decreases with the increase of deviator stress.
- The finite element analysis shows that the maximum vertical displacement in case of using MSWIBA material is less than the that in case of using soil material. It is recommended that MSWIBA can be used as construction material such as roadbed and foundation layers.

5. ACKNOWLEDGMENTS

The authors gratefully acknowledge the financial support from the Ministry of Education and Training, Vietnam (Code B-2019-GHA10). In addition, the authors appreciate anonymous reviewers for giving us valuable comments to improve the paper.

6. REFERENCES

[1] Lynn C.J, Ghataora G.S, Dhir R.K, Environmental impacts of MIBA in geotechnics and road applications. Environ Geotech. 2018, 5(1).
[2] Yang Z, Ji R, Liu L, Wang X, Zhang Z, Recycling of municipal solid waste incineration by-product for cement composites preparation. Constr Build Mater, 2018.
[3] Ahmed A.T, Khalid H.A, Effectiveness of novel and traditional treatments on the performance of incinerator bottom ash waste. Waste Management Journal, 2011.
[4] Toraldo E, Saponaro S, Careghini A, Mariani E. Use of stabilized bottom ash for bound layers of road pavements. J Environ Manage, 2013,121, 117-23.
[5] Chimenos J.M, Fernández A.I, Miralles L, Rosell J.R, Ezquerra A.N, Change of Mechanical Properties during Short-Term Natural Weathering of MSWI Bottom Ash. Environ Sci Technol, 2005, 39(19):7725-30.
[6] Becquart, F., Bernard, F., Abriak, N. E., and Zentar, R, Monotonic aspects of the mechanical behaviour of bottom ash from municipal solid waste incineration and its potential use for road construction. Waste Management, 2009.
[7] Wiles C., and Shepherd, P., Beneficial Use and Recycling of Municipal Waste Combustion Residues a comprehensive resource document, 1999.
[8] Lentz, D., Demars K.R., Long, R.P. and Garrick, N. W., Performance and analysis of incinerator bottom ash as structural fill. University of Connecticut, JHR 94-232, 1994.
[9] Lin, C., Weng, M., and Chang, C., Effect of incinerator bottom-ash composition on the mechanical behavior of back fill material. Journal of Environmental Management, 2012, 113, 377-382.
[10] Muhunthan, B., Taha, R., Said, J., and Muhunthan, B. (2012): Geotechnical Engineering Properties of Incinerator Ash Mixes Geotechnical Engineering Properties of Incinerator Ash Mixes. J. Air Waste Manage. Assoc., 2004, (54) pp 985-991.
[11] Sormunen, L. A., & Kolisoja, P. (2018). 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(2), 252-270.
[12] K. M. N. Saquib Wani & B. A. Mir: A comparative laboratory scale study on the effect of waste boulder crusher dust and cement in stabilising marginal sediments. Geomechanics and Geoengineering, 2020
[13] Rahim, A. M., Subgrade soil index properties to estimate resilient modulus for pavement design. International Journal of Pavement Engineering, 2005, 6(3), 163-169.
[14] AASHTO. AASHTO Guide for Design of Pavement Structure 1993. Washington DC: The American Association of State Highway and Transportation Officials; 1993.