Vol. 3, No. 1, 2021

https://doi.org/10.23939/jtbp2021.01.085

Serhiy Solodkyy, Volodymyr Hidei, Iurii Sidun, Oleksii Hunyak and Yuriy Turba

USING WASTEPAPER SLUDGE ASH (WSA) AS A MATERIAL FOR SOIL STRENGTHENING FOR THE CONSTRUCTION OF LAYERS OF PAVEMENT

Lviv Polytechnic National University
Department of Highways and Bridges,
gideivolodymyr@gmail.com

The article considers the possibility of using wastepaper sludge ash (WSA) as a soil reinforcement material for the construction of layers of road wear. Loamy sand, sandy loam, silty clay loam, silty clay were chosen as soils for strengthening. The maximum density of the soil skeleton at optimum humidity was established by the method of Proctor. Wastepaper sludge ash and Portland cement grade 400 were used separately for soil strengthening. Six compositions of strengthened soil for each type of soil were investigated according to the strength criterion of water-saturated samples at the age of seven, fourteen and twenty-eight days. The research results indicate that wastepaper sludge ash can be used to strengthen different types of soils with the achievement of following grades of stabilized soil: M10, M20, M40.

Key words: wastepaper sludge ash, Portland cement, soil strengthening, maximum density, optimal soil moisture content, compressive strength.

Introduction

Nowadays, in the world there is a massive problem of waste utilization especially of industry by-products. It creates a significant number of dumps, which occupy large areas of land in Ukraine. One of the utilization methods is their use in construction. Scientific papers (Sobol, 2020; Ahmad 2013, Frias, 2015; Segui, 2015; Ferreiro, 2013, Fava, 2011, Cusido, 2015) suggest the use of waste, called wastepaper sludge ash (WSA) as an additional cementing material for mineral binders in building composites, and in road construction in particular. It has been discovered (Hidei, 2020) that WSA can be used as a mineral powder for traditional hot asphalt concrete. The results of previous research (Sobol, 2020) showed that WSA produced by PJSC “Kyiv Cardboard and Paper Mill” have a binding properties and form a stable hardening systems.

In world practice, mineral, organic and complex binders are used to strengthen soils (Solodky, 2017). The following materials are used as independent organic binders for soil strengthening: road bitumens, bitumen emulsions, bitumens and liquid bitumen polymers. Mineral materials such as Portland cement, lime, ground granulated blast furnace slag and fly ash can be successfully used to strengthen the soil as stand-alone stabilizing agent or in specific combination, the ratio of which provides the necessary properties of the reinforced material.

Several attempts were made to test the WSA`s ability to stabilize soils. Authors (Khalid, 2012) have discovered, that clay soil stabilized using 10 % WSA considered effective to enhance clay soil strength for long periods and to enhance the CBR value. Other research results (Baloochi, 2020) have shown that use of wastepaper fly ash as a main binder is well suited for soil stabilization, although care should be taken to avoid possible soil expansion.

The authors put forward the idea of replacing cement with WSA to strengthen different types of soils. Additives of various functional purposes are also used to optimize the process of structure formation and meet the requirements for the physical and mechanical properties of soils reinforced with binders. In our case, tartaric acid acted as such an additive, which makes it possible to delay the WSA`s setting time.

Target of this article

Comparison of strength characteristics of different soil types reinforced with Portland cement and WSA.

Technical use

The following types of soils were used in the research according to (DSTU B B.2.1-17: 2009): loamy sand, sandy loam, silty clay loam, silty clay.

Portland cement CEM II/ B-S 32,5 R (EN 197-1 2000) produced by PJSC "Mykolayivcement" was introduced into the soil as reinforcing components, WSA was provided by PJSC "Kyiv Cardboard and Paper Mill" and combined with tartaric acid for . The chemical composition of WSA is given in table.1.

Table 1

Chemical composition of waste paper sludge, wt %

Oxides content, wt. %							
SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	LOI	∑
26.44	15.36	1.16	49,84	2.16	0.45	4.59	100.0

At the first stage of the study, the physical and mechanical properties of the type of soil used (Table 2) and the maximum density of the soil skeleton at optimal humidity for different types of unfortified soils (Table 3) were established. Determination was performed by the Proctor method (ASTM D 698-91), with the inner diameter and height of the mold for sealing were 101.6 mm and 116.4 mm, respectively. The number of layers in the compaction mold was 5, the number of strikes on each layer of soil – 25. The weight of the compaction load – 4.5 kg, and the height of fall – 457.2 mm.

Table 2

Determining the type of soil

No. p/p	Physico-mechanical parameters	Soil type according to DSTU B B.2.1-2-96			
		Loamy sand	Sandy loam	Silty clay loam	Sandy clay
1	2	3	4	5	6
1	Humidity w, %	7.2	13.8	13.4	12.2
2	Disturbed structure soil density ρ, g/cm^3	1.78	2.09	2.11	2.16
3	The density of soil particles ρ_s, g/cm^3	2.66	2.78	2.69	2.76
4	Density of dry soil ρ_d, g/cm^3	1.66	1.84	1.86	1.93
5	Pores n, %	37.6	33.8	30.9	30.1

Continuation of Table 2

1	2	3	4	5	6
6	Porosity coefficient, e	0.602	0.511	0.446	0.430
7	Humidity at the yield strength W_L, %	–	18.2	33.4	41.3
8	Humidity on the verge of rolling Wp, %	–	17.0	25.2	23.1
9	The number of plasticity Ip = W_L–Wp, %	–	1.2	8.2	18.2
10	Fluidity index (consistency), $I_L=(W-W_p)/(W_L-W_p)$	–	-2.67 (firm)	-1.44 (firm)	-0.60 (firm)
11	Specific adhesion, kPa	4.96	18.6	47.0	81.0
12	The angle of internal friction φ, °	31.9	29.4	26.0	21.0
13	Deformation modulus E, MPa	22.8	27.1	34.0	28.0
14	Water saturation coefficient, Sr	0.32	–	–	–

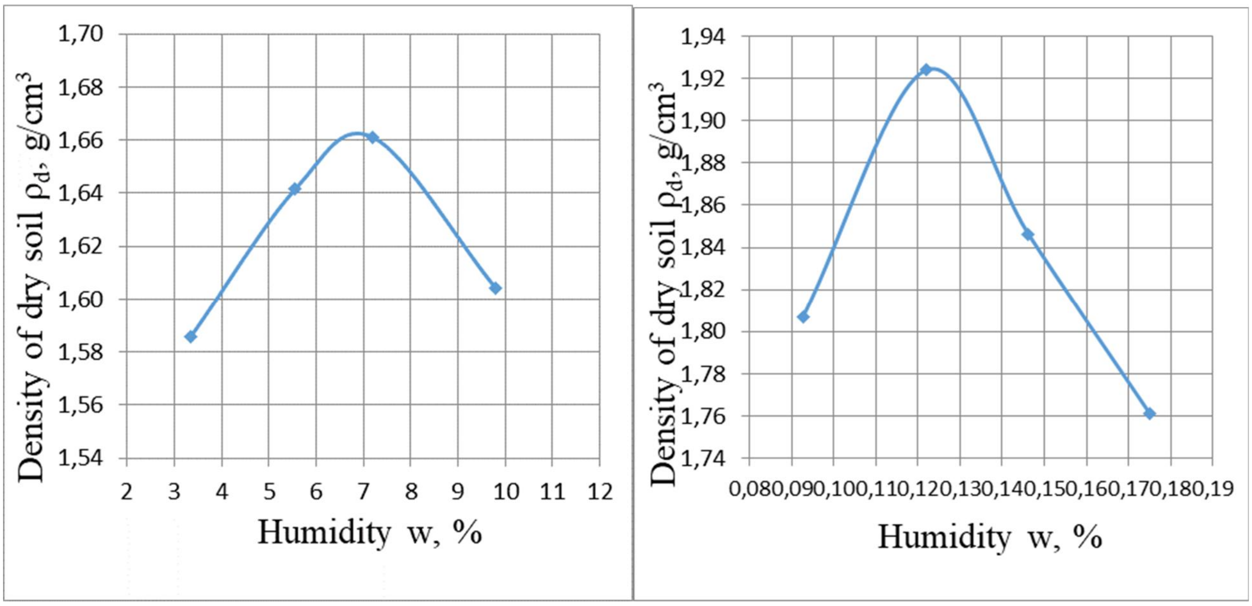
According to DSTU 8801: 2018 clays with a plasticity number greater than 22 are not suitable for strengthening with binders. In our version (Table 2) such soils are not detected.

Table 3

The results of laboratory tests of different types of soils by the method of Proctor, to determine the maximum density of dry soil at optimum humidity

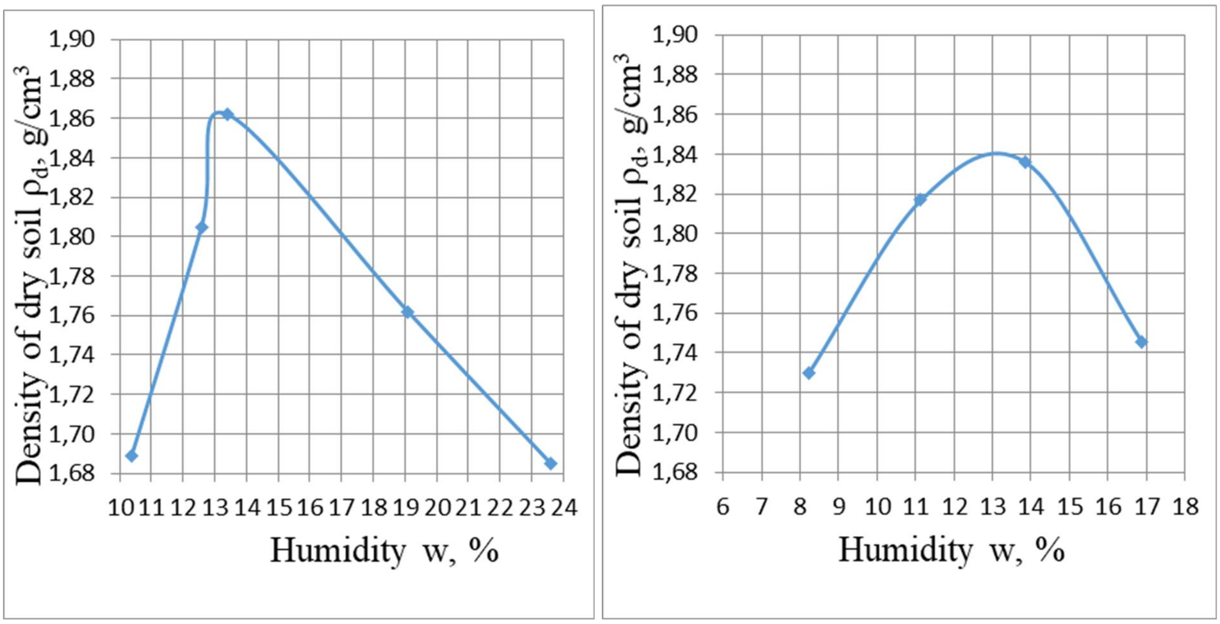
Type of soil	Soil characteristics	No. tests			
		1	2	3	4
Loamy sand	Humidity	3.3	5.6	7.2	9.8
	Soil density in the wet state m/V = ρ, g/cm^3	1.639	1.733	1.781	1.761
	Density of dry soil ρ/(1 + c) = ρ_d, g/cm^3	1.586	1.642	1.661	1.604
Sandy loam	Humidity	8.2	11.1	13.8	16.9
	Soil density in the wet state m/V = ρ, g/cm^3	1.872	2.019	2.090	2.040
	Density of dry soil ρ/(1 + c) = ρ_d, g/cm^3	1.730	1.817	1.836	1.746
Silty loam	Humidity	12.6	13.4	19.1	23.6
	Soil density in the wet state m/V = ρ, g/cm^3	2.033	2.112	2.098	2.083
	Density of dry soil ρ/(1 + w) = ρ_d, g/cm^3	1.805	1.862	1.762	1.685
Sandy clay	Humidity	0.083	0.117	0.141	0.157
	Soil density in the wet state m/V = ρ, g/cm^3	1.937	2.043	2.102	2.054
	Density of dry soil ρ/(1 + w) = ρ_d, g/cm^3	1.788	1.829	1.843	1.775

According to Table 2 and Figure 1,2 the maximum density is achieved at a humidity of loamy sand – 6.9 wt. %, sandy loam – 13 wt. %, silty loam – 13.2 wt. % And sandy clay – 12.3 wt. %.



a *b*

Fig. 1. Dependences of dry soil density on moisture:
a – the maximum density of dry soil at the optimum humidity of silty loam;
b – the maximum density of dry soil at the optimum humidity of sandy loam



c *d*

Fig. 2. Dependences of dry soil density on moisture:
c – the maximum density of dry soil at the optimum humidity of loamy sand;
d – maximum density of dry soil at optimum humidity of light sandy clay

The next stage of the study was to study the ultimate compressive strength of fortified WSA soils. Soil samples were formed according to (DSTU B B.2.1-309: 2016). The compositions of soils reinforced with binder and the consumption of materials for the formation of samples are given in Table 4. For each type of soil to be strengthened, 6 compositions were designed. The components of the stabilized soil were calculated to be more than 100 % by mass of the corresponding soil type.

Determination of the ultimate compressive strength of stabilized soils was carried out in accordance with DSTU B B.2.7-309: 2016.

Table 4

Consumption of materials

No. of composition	Components of fortified soil over 100 % by mass of the corresponding soil type			
	WSA, w_t. %	Portland cement, w_t. %	*Water to the optimum soil moisture + depending on the water consumption of the binder, wt. %	Tartaric acid
1	–	–	–	–
2	–	6 %	+ 0.3	–
3	–	10 %	+ 0.3	–
4	8 %	–	+ 0.38	1.0 wt. % of WSA
5	11 %	–	+ 0.38	
6	14 %	–	+ 0.38	
* Water was added to the optimal soil moisture according to table. 1 and Fig. 1,2 and additionally depending on the water consumption of the binder and its type				

According to Table 5, the highest strength indicators were predicted by soils of all types with a cement content of 10 % by mass. Depending on the amount of added WSA and the type of fortified soil, it is possible to achieve soil strength that corresponds to the grades M10, M20, M40 in accordance with DSTU 8801: 2018. The most suitable soil for strengthening according to the criterion of strength was light dusty clay, as in the role of Portland cement and WSA.

Table 5

The results of tests of the ultimate compressive strength of soils of different types

Type of soil	No. of composition	Compressive strength, MPa at the age of days				Compressive strength of water-saturated samples, MPa for grades according to DSTU 8801: 2018
		3	7	14	28	
Loamy sand	1	-	0.1	0.3	0.4	–
	2	0.6	0.8	1.0	1.3	M10
	3	1.3	1.7	2.5	3.5	M20
	4	0.2	0.3	0.4	0.5	–
	5	0.3	0.5	0.7	1.0	M10
	6	0.5	0.7	1.0	1.4	M10
Sandy loam	1	0.05	0.1	0.3	0.4	–
	2	0.7	1.2	1.9	2.5	M20
	3	1.3	1.8	2.5	3.7	M20
	4	0.2	0.4	0.6	0.8	–
	5	0.5	0.8	1.0	1.3	M10
	6	0.7	1.1	1.8	2.3	M20
Silty loam	1	0.2	0.4	0.7	0.8	–
	2	1.7	2.5	3.7	5.0	M40
	3	2.8	4.1	5.0	6.9	M60
	4	0.6	1.0	1.6	2.1	M20
	5	0.9	1.4	2.2	2.9	M20
	6	1.4	1.9	2.8	3.8	M20
Sandy clay	1	0.6	0.7	1.1	1.3	M10
	2	2.8	4.1	5.0	6.8	M60
	3	4.4	6.8	8.3	11.2	M60
	4	2.4	3.5	4.1	5.5	M40
	5	2.8	3.9	4.9	5.6	M40
	6	3.4	4.7	5.2	6.9	M60

In general, it is possible to use WSA as a material for strengthening different types of soils for the construction of layers of pavement according to the criterion of compressive strength. But for the final conclusion, regarding the use of WSA for soil strengthening, it is necessary to establish the coefficient of frost resistance of the experimental samples, which will be the next stage of the study.

Conclusions

Wastepaper sludge ash was found to have binding properties when strengthening different types of soil. According to the criterion of compressive strength of strengthened soil, wastepaper sludge ash in combination with tartaric acid is less effective than Portland cement. However, with the appropriate dosage and depending on the type of soil, the following grades of strengthened soil can be achieved: M10, M20, M40 and M60.

References

Sobol K., Solodkyy S., Petrovska N., Belov S., Hunyak O. & Hidei V. (2020). Chemical Composition and Hydraulic Properties of Incinerated Wastepaper Sludge. Chemistry & Chemical Technology. 14. 538–544. 10.23939/chcht14.04.538.

Ahmad S. (2013). Study of concrete involving use of waste paper sludge ash as partial replacement of cement JOSR. J. Eng. Volume 3, Number 11: P. 6–15. https://doi.org/10.9790/3021-031130615

Frias M., Rodriguez O., Sanchez de Rojas M.I. (2015). Paper sludge, an environmentally sound alternative source of MK – based cementious materials. Contruction and Bulding Materials. Vol. 74, 37–48. https://doi.org/10.1016/j.conbuildmat.2014.10.007

Frias M., Garcia R., Vigil R.,Ferreiro S (2001). Calcinations of art paper sludge waste for the use as a supplementary cementing material. Appl Clay Sci, 42(1-2), 189–193.

Segui P., Aubert J.E., Husson B., Measson M. (2015). Characterization of wastepaper sludge ash for its valorization as a component of hydraulic bilders. Applied Clay Science, Vol. 57, 79–85. https://doi.org/10.1016/j.clay.2012.01.007

Ferreiro S., Frias V., Vigil de la Villa R., Sanchez de Rojas M. (2013). The influence of thermo activation of art paper sludge on the technical properties of blended Portland cements. Cem. Concr. Compos. 37,136-142.DOI: 10.1016/j.cemconcomp.2012.11.005

V. Hidei, Iu. Sidun, O. Hunyak, S. Stanchak, V. Bidos (2020). Application of wastepaper sludge ash as mineral powder for hot asphalt concrete mix JTBP. 2020; Vol. 2, Number 2, 42–47 https://doi.org/10.23939/jtbp2020.02.042

ASTM D 698 Standard Test Methods for Laboratory Compaction Characteristics of Soil Using Standard Effort

G. Fava; M. Letizia Ruello, V. Corinaldesi (2011) Paper Mill Sludge Ash as Supplementary Cementitious Material; Journal of Materials in Civil Engineering Vol. 23, Issue 6 https://doi.org/10.1061/(ASCE)MT.1943-5533.0000218.

Solodky S., Topylko N., Turba Yu., Hrymak O., Novytskjy Y. (2017) Optimization of the cement compounds with the aim of increase of its physical-mechanical indicators Teoriia i praktyka budivnytstva. Number 877. P. 199–211.

Cusido J., Cremandes L., Suricano C., Devant M.: Appl. Clay Sci., 2015, 108, 191. https://doi.org/10.1016/j.clay.2015.02.027

Lisbona, A., Vegas, I., Ainchil, J., & Ríos, C. (2012). Soil stabilization with calcined paper sludge: laboratory and field tests. *Journal of Materials in civil engineering*, *24*(6), 666–673. https://doi.org/10.1061/(ASCE)MT.1943-5533.0000437

Khalid, N., Mukri, M., Kamarudin, F., & Arshad, M. F. (2012). Clay soil stabilized using waste paper sludge ash (WPSA) mixtures. *Electronic Journal of Geotechnical Engineering*, 17, 1215–1225.

Baloochi, H., Aponte, D., & Barra, M. (2020). Soil Stabilization Using Waste Paper Fly Ash: Precautions for Its Correct Use. *Applied Sciences*, 10(23), 8750. ttps://doi.org/10.3390/app10238750

С. Й. Солодкий, В. В. Гідей, Ю. В. Сідун, О. М. Гуняк, Ю. В. Турба
Національний університет “Львівська політехніка”,
кафедра автомобільних доріг та мостів

ВИКОРИСТАННЯ МАКУЛАТУРНОГО СКОПУ ЯК МАТЕРІАЛУ ДЛЯ УКРІПЛЕННЯ ҐРУНТІВ ДЛЯ СПОРУДЖЕННЯ ШАРІВ ДОРОЖНОГО ОДЯГУ

У світі та в Україні існує проблема утилізації відходів і побічних продуктів промисловості, відвали яких займають великі площі земель. Одним із методів утилізації є використання їх у будівництві. У статті розглянуто можливість використання такого відходу, як макулатурний скоп, для укріплення ґрунтів робочого шару земляного полотна та для спорудження шарів дорожнього одягу. Для укріплення використано чотири типи ґрунтів: пісок пилуватий, супісок пилуватий, суглинок легкий пилуватий та глина легка пилувата. Тип кожного використаного ґрунту встановлено на основі фізико-механічних властивостей. Визначено також максимальну щільність ґрунту за оптимальної вологості наведених типів ґрунтів за методом Проктора. Для укріплення ґрунтів різних типів використано окремо макулатурний скоп у комбінації із винною кислотою, що дає змогу сповільнити терміни тужавіння ґрунту та збільшити пластичність композиції. Для порівняльних досліджень в статті використано портландцемент марки 400. В роботі досліджено шість складів укріпленого ґрунту для кожного із чотирьох типів ґрунтів за критерієм границі міцності водонасичених зразків у віці семи, чотирнадцяти та двадцять восьми діб. Результати досліджень вказують на те, що макулатурний скоп може використовуватись для укріплення різних типів ґрунтів із досягненням марок укріпленого ґрунту: М10, М20, М40 та М60. Для остаточного висновку про застосування макулатурного скопу як матеріалу для укріплення ґрунтів робочого шару земляного полотна та для спорудження шарів дорожнього одягу потрібно встановити коефіцієнт морозостійкості зразків запропонованих складів.

Ключові слова: макулатурний скоп, портландцемент, укріплення ґрунтів, максимальна щільність, оптимальна вологість ґрунту, границя міцності на стиск.