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Application of ash and slag mixtures in the road construction: current directives and recommendations

Abstract: Nowadays civil engineering is constantly searching for cheaper substitutes of already known and commonly used building materials. Especially road and railway industries focus on reducing the costs, as large objects like highways and railroads can require high material usage in order to prepare required foundation. Therefore, the use of waste (in particular fly ash and slag mixtures) as a foundation material not only can bring savings but also is environment friendly, as it creates new ways to dispose waste. However, it is problematic to use the mentioned materials due to ambiguities revolving around current recommendations for their application. In the article, a comprehensive review of the fly ash and slag mixtures use in civil engineering is made. Guidelines and requirements for the use of waste material as a road foundation material are discussed. Discrepancies between the recommendations are analyzed and the potential changes are suggested. The article is also the basis for further investigation of fly ash and slag mixtures composition improvements.

Keywords: Ash and slag mixtures; Base layer

Introduction

In the mining and energy industries, one of the main problems is proper management of the generated waste. One of the solutions is well-thought-out storage and subsequent land reclamation. Another approach is the utilization of the generated waste by using it for other purposes, eg materials production. Due to the wide possibility of obtaining substitutes for classic building materials, the construction industry is increasingly using poorer waste as an ingredient in various types of mixtures. Particularly popular here are ash-slag mixtures, which are used in the construction of road embankments and road surfaces [7,10]. Such a solution gives undoubted benefits in the form of reducing material costs and managing a lot of "unwanted" waste. Despite the obvious advantages, one should bear in mind the fact that the use of ash and slag mixtures in the construction implies specific conditions and requirements for the implementation of individual layers. All the requirements regarding the parameters of the mixture material itself, as well as the way it is used, are provided in the relevant national regulations.

In the current situation in road construction, the guidelines published by GDDKiA in the Technical Conditions (notebooks 1-5) are used in the design. In Technical Conditions No. 5: "Mixtures bound by a hydraulic binder to national roads" (WT-5) [11] are given parameters

for mixtures, according to which such materials are evaluated, in terms of their suitability for use in road construction. In addition, manufacturers of ash and slag mixtures refer to the provisions contained in [11] refer to them in the specifications of materials they manufacture. Such a practice does not take into account the important factor that is the limitation of the regulations on the basis of which the WT-5 was constructed. The WT-5 guidelines created in 2010 are based on standards [3,5], which changed in 2013 and were replaced by [4]. Therefore, the article reviews the guidelines specifying the suitability of a given mix of material for use in road construction, taking into account the changes introduced in 2013. The differences between the updated standard guidelines [4] and the WT-5 recommendations are indicated [11].

General recommendations for the use of ash and slag mixtures

By means of ash and slag mixture, we understand the residue from the combustion of hard coal and biomass, which, thanks to its very good thickening properties, is used in construction. Such material can be used to make the bottom layers of road embankments, provided that they are in dry places or are isolated from water. Due to the high sensitivity of the material to water, a number of additional conditions are recommended to protect the mix against harmful interactions [6]:

- the humidity of the compacted mixture must not deviate from the optimum humidity from +2% to - 4%,
- it is necessary to make a layer separating the layer from an ash-slag mixture with a thickness of about 50 cm and a filtration coefficient of k≥6 · 10-5 m / s,
- upper layers require transverse slopes of about 4%,
- upper layers must protect layers from ash-slag mixtures against excessive moisture,
- protect the slopes with a layer of erosion to the memento of plant cover.

In addition, adequate compaction of the mix must be ensured. Compaction assessment is carried out by determining the value of the compaction index for the subsoil. The recommended values are given in Table 1.

Tab. 1. The values of the compaction index for the subsoil under the embankment [6]

Embankments with a height	**I_s minimum value**
Up to 2 meters	0.97
Above 2 meters	0.95

The ash slag mixes can also be used as layers of the road surface structure. The catalog of typical susceptible and semi-rigid surfaces [2], indicates the preferred layers of the road surface structure in which an ash-slag mixture can be used. It is assumed that the layer made of ash and slag mixture should have the appropriate strength specified in the Catalog [2].

Tab. 2. Layers of pavement construction using ash and slag mixtures

Layer type	**Mixtures related to hydraulic binders**
wear	Does not apply
binding	Does not apply
basic foundation	KR1-KR7
auxiliary foundation	KR3-KR7
frost protection layer	KR1-KR4
layer of improved substrate	Does not apply

As you can see the catalog of typical susceptible and semi-rigid surfaces does not provide for the use of ash-slag mixtures for making the layer of the improved substrate. Nevertheless, the WT-5 guidelines assume that "mixtures related to fly ash may be applied layers of improved substrate and foundation of an auxiliary road surface transferring category from KR1 to KR6" according to the recommendations presented in table 4. 3 Individual types of mixtures according to WT-5 they are characterized by the appropriate parameters of grain size and permeability as well as the amount of binder used in the form of ash. Detailed guidelines on the classification and use of individual types of mixtures can be found in Technical Specification No. 5.

Tab. 3. The intended use of fly ash-bound mixtures [11]

mixture	**Auxiliary foundation layer**			**Substantial foundation layer**			**Improved substrate layer**
	KR1-KR2	**KR3-KR4**	**KR5-KR6**	**KR1-KR2**	**KR3-KR4**	**KR5-KR6**	**KR1-KR6**
1 0/31.5 type	+	+	+	+	+	+	+
2 0/22.4 type	+	+	+	+	+	+	+
2 0/16 type	+	+	+	+	+	+	+
2 0/11.2 type	+	+	+	+	+	+	+
3 0/11.2 type	-	-	-	-	-	-	+
4 type	±	±	±	±	±	±	±
5 type	+	+	+	-	-	-	+
where: + recommended mixture; - the mixture is not approved for use; ± destiny depending on the declared properties of the mixture							

In addition, such mixtures meet the guidelines contained in the PN-S-06103 standard "Roads. Ash concrete foundation "[9], which determines what parameters the material used for the foundation should exhibit. Theoretically, therefore, the ash-slag mix can be used as a layer of the improved substrate, provided that the following requirements are met [6]:

- Subsoil substrate layers made of ash-slag mixture must obtain the value of the degree of compaction: Is≥1.0 for KR1- KR2 and Is ≥0.97 for KR3- KR6
- the mixture should be laid at a temperature of ≥ 5 ° C during the dry season until the end of October,
- the mixture should be compacted on the day of its laying and before adverse weather changes, and before laying next layers of the structure at optimal humidity with a deviation of ± 2%. The density value should be: Is ≥0.98 for KR1- KR2 and Is ≥1.03 for KR3- KR6, respectively
- care of layers of ash concrete should take place on one of three methods proposed by the standard: spraying with asphalt emulsion, spraying with coating preparations, covering with a 3 cm thick bitumen layer,

It should be emphasized here that practically for all applications of ash-slag mixtures, special emphasis is placed on the protection of the mixture against water. It should, therefore, be considered how the weather conditions will affect the time and costs of building the facility using ash and slag mixtures.

Characteristics of properties of ash slag mixtures.

In addition to the requirements regarding the conditions of use and construction technology of ash and slag mixtures, the legal regulations [2] also specify what parameters should be used for the mixtures used. In the general case, the mixture is evaluated on the basis of a set of tested parameters listed in table 4, and then classified as a mixture of a given type. The types

of mixtures distinguished by WT-5 are quoted in Chapter 2. It should be noted here that the WT-5 distinguishes 5 types of ash-slag mixtures referring to [3]. PN-EN 14227-3: 2013 (updated version of the standard [3]) distinguishes 6 types of mixtures, introducing at the same time changes in the description of each mixture. This results in a lack of precision when it comes to determining the type of mixture and, consequently, its suitability for use as a building material. In addition, differences also appear between the standards [3,4] on which the WT-5 is based and the Technical Conditions themselves [11].

In the case of the first type of incompatibility, there are between WT-5 and PN-EN 14227-3: 2007 and PN-EN 14227-3: 2013, which assume the use of the same types of sieves. The WT-5 uses a different set, as shown in Table 5.

Tab. 4. Requirements for dust and slag mixtures according to [11]

Feature	Unit	Normalized value
The minimum content of the sand-gravel fraction	[%]	≥35
Maximum content of grains below 0.075mm	[%]	≤75
The minimum content of unburned coal	[%]	≥10
Maximum volume density of the skeleton after compaction in the Proctor apparatus according to method I or II,	[g/cm^2]	≥1
Load index after 4 days of water saturation	[%]	10
Linear swelling of the material: no load	[-]	≤0.2
with a load of 3 kN / m2	[-]	≤0.5
Angle of internal friction	[°]	≥20
Passive capillarity	[m]	≤2.0
Sulphate content (calculated as SO3)	[%]	<3.0

Tab. 5. Granulation of type 1 mixture

Diameter of the mesh sieve [mm]	WT-5		Norms [3, 4,]		Difference	
	Min	Max	Min	Max	Min	Max
40	100	100	100	100	0	0
31,5	85	100	85	100	0	0
25	no sieve	no sieve	75	100	-	-
20	no sieve	no sieve	66	95	-	-
22,4	70	100	no sieve	no sieve	-	-
11,2	51	83	no sieve	no sieve	-	-
10	no sieve	no sieve	48	82	-	-
4	51	68	34	68	17	0
2	34	68	26	58	8	10
1	26	58	no sieve	no sieve	-	-
0,5	16	38	16	38	0	0
0,25	13	30	13	30	0	0
0,063	7	18	7	18	0	0

For a type 2 blend, the standard entries [4] are distinguished by three subtypes (Type 2- 0/20, Type 2- 0/14, Type 2- 0/10). WT-5 recommendations again differ from the aforementioned normative recommendations, suggesting the following division of subtypes of the second type mixture: Type 2- 0 / 22.5, Type 2- 0/16, Type 2- 0 / 11.2. In addition, the standard [4] within the classification of the mixture takes into account the target category of ground soil (G1 or G2), for which the mixture is to be used. At the same time, WT-5 does not

differentiate subtypes of the second mixture due to the planned substrate category. Table 6 presents an example of the requirements of the standard [4] and Technical Guidelines 5 for the granulation of the mixture for Type 2.

Tab. 6. Comparison of the grain size of mixtures 0/16 according to WT-5 from 0/14 from the norms

Sieve	WT-5		PN-EN 14227-3:2013			Difference		
	Min	Max	Min	G1	G2	Min	G1 -maxWT5	G2-maxWT5
25	100	100	100	100	100	0	0	0
16	90	100	no sieve	no sieve	no sieve	-	-	-
14	no sieve	no sieve	84	100	100	-	-	-
11,2	73	98	no sieve	no sieve	no sieve	-	-	-
10		no sieve	73	95	97	-	-	-
6,3	no sieve	no sieve	60	81	87	-	-	-
5,6	43	76	no sieve	no sieve	no sieve	-	-	-
4	38	71	48	67	74	-10	4	-3
2	26	56	35	51	57	-9	5	-1
0,5	13	32	20	32	35	-7	0	-3
0,25	10	23	15	25	28	-5	-2	-5
0,063	4,5	11	9	18	19	-4,5	-7	-8

The classification conditions for the type 3 blend remain virtually unchanged between the WT-5 and the new standard [4]. The occurring, minor differences refer to the grain composition of the mixture and are presented in Table 7. The new standard gives greater freedom in the design of type 3 blends, with the proviso that the diameter of the mesh D will be no more than 6.3 mm. The maximum values of the immediate load index have also been updated, which is given for the type 3 mixture in WT-5 is IPI40, while [4] adds the next IPI50 value.

Tab.7. Differences in the grain size of the type 3 mixture

Document	**Sieve**		
WT5	11.2	5.6	0.063
PN-EN 14227-3:2013	2D	D	
Mass passing through a sieve, %	100	≥85	≤35

In the case of type 4 mixtures, there are no differences between WT-5 and PN-EN 14227-3: 2013. In accordance with the requirements [4,5], the parameters of the mixture are to be determined in accordance with EN-993 and provided by the supplier. The mixture marked in the standard [4] No. 6 corresponds to the Type -5 mix in WT-5. It is a mix whose main ingredient and a binder is fly ash. The new mixture described in [4] referred to as Type-5 is characterized by the grain composition shown in Table 8.

Tab. 8. Granulation for type 5 mixture (according to PN-EN 14227-3: 2013)

Sieve (mesh diameter in mm)	45	31.5	20	10	4	2	0.5	0.25	0.063
Mass passing through a sieve, %	100	≥85	≥66	≥48	≥34	≥28	≥16	≥13	7-35

The requirements for silica ashes used in ash-slag mixtures, to which individual manufacturers refer, are included in WT-5 and the standards on which this document is based

[3,5], however in the light of the new standard PN-EN 14227-4 2013 10 [4], the parameters included in tab. 9

Tab. 9. Differences between WT-5 and the new standard PN-EN 14227-3:2013

Feature	Value	
	WT-5 2010	PN-EN 14227-3:2013
Granulation 90μm sieve 45μm sieve	 ≥ 70% ≥ 40%	 Lack ≥ 60%
Loss on ignition	≤ 10% m/m	≤ 15% m/m
Sulfuric anhydride	≤ 4% m/m	≤ 4% m/m
Free calcium oxide	≤ 1% m/m	≤ 1.5% m/m
Water content	≤ 1% m/m	≤ 1% m/m
Pozzolanic activity	Declared	Declared

Analyzing the changes that have been made in PN-EN 14227-3: 2013, it can be noticed that the requirements for silica ashes are less restrictive than in the case of WT-5 (and "old" standards). The required graining has changed, the increase from 40 to 60% of the material passing through the 45μm screen and the lack of a 90μm screen requirement. The tolerance for the loss of roasting (by 5%) and for the content of calcium oxide from 1 to 1.5% m / m was also increased. Other features remain unchanged.

Summary

A large number of projects in which ash-slag mixtures have been applied to the improved substrate layer suggest that the recommendations of the national guidelines should be reviewed taking into account updated standards. The WT5 national guidelines are a simple tool for efficient selection and evaluation of materials to be used, however, it is necessary to consider changing the document of Technical Conditions No. 5 due to the lack of validity of standards on which this document is based. In addition, despite the fact that the catalog of typical flexible and semi-rigid structures does not envisage the use of dust and slag mixtures for layers of the improved substrate, it should be considered how this mixture would behave as this element of roadway construction. The possibility of modifying ash-slag mixtures should be considered here. The use of additives, e.g. in the form of cement, allows the strength parameters of the material to be improved [1,9]. Modification of ash and slag mixture may also have a positive effect on its resistance to change of atmospheric conditions. This would avoid problems related to its laying and care. Definitely, ash-slag mixtures as a post-industrial material, are environmentally friendly and their use in road construction can have a positive impact on the improvement of the quality of the constructed structure by providing a high load-bearing capacity of the bottom layers of the road surface structure.

Source materials

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