UDC 621.9

Part 3

ASH AND SLAG HANDLING

3.5. Applications of ash and slag from power coals

3.5.2.5. Mixed type binding systems. A sustainable alternative for RCC road pavements

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ABSTRACT

The strength potential of alternative binders such as fly ashes, slags, natural pozzolans and metakaolin is not usually exploited to the maximum since their physicomechanical characteristics are rarely understood in detail. Provided that a thorough knowledge of the characteristics of supplementary cementing materials exists, the combination of high volume of them in a binding system could offer a sustainable alternative. In this paper, a binding system with high volume of calcareous fly ash and natural pozzolan and only with 20 % by mass Portland clinker has been used for the bedding of part of a rural road, constructed by EGNATIA ODOS S.A. in Greece. The concrete mixture and its properties in fresh and hardened state, as well as its technical details, are reported. Problems during construction are mentioned and short and long term test results concerning the concrete road pavement performance are also given.

Keywords: fly ash, natural pozzolan, Portland clinker, binding system, RCC road pavement, compaction, strength

INTRODUCTION

Mixed type binding system is usually called the combination of powdered materials in a system which develops cementing properties with water under environmental conditions and strength after setting and hardening. The concept of exploiting the potential of mixed type binding systems is well known in construction even from prehistory, where pozzolan was added to lime in order to increase strength and resistance to moisture.

From the 19th century and up to now, Portland cement predominates in the construction industry, but under the pressure of the economy and the need for sustainability, the use of mixed-type binders has increased remarkably, irrespective of the way of their incorporation into the concrete mixture; either in the form of blended type cements or as a sum of separate ingredients directly added to the batch mixer. However, globally, only a very small percentage of these alternative materials (about 10 % of the output of each [1]) is used beneficially in construction and there is a lot of future in exploiting their potential.

A first simple step for sustainability integration in construction is to make local industrial by-products, such as fly ashes and slags, beneficial in the structural sector. Road pavement construction is a sector that could absorb large volumes of cementitious by-products in sub-base, base or even surface concrete layer construction. Specifically, the roller compacted concrete pavement are concrete pavements suggested for heavy or light industrial pavements, country roads, commercial areas and airports, mostly because they are quickly bedded without formwork and steel reinforcement. RCC provides an economical, strong and durable solution. Besides, only a typical asphalt paver is required for placement with minimum labor. The required strength usually ranges from 20 to 35 MPa and the thickness after compaction from 20 to 25 cm, while it is preferable to have one layer bedding in order to avoid cold joints. The use of fly ash or slags in RCC road pavement has a history in many countries such as USA, Austria, Australia and many relevant technical guidelines exist [2-4]. However, a pilot construction with locally available binding systems and under regional environmental conditions is necessary for establishing the details, such the paving and vibrating scenarios. Therefore, a step by step strategy must be followed, such as:

- Development of the mixed-type binding system and assessment of its quality
- Proportioning the concrete mixture for roller compaction
- Testing properties in the fresh and hardened state
- Pilot construction of part of a road pavement
- Measurement of long term strength and resistance to frost scaling

THE CONSTRUCTION OF A RCC ROAD PAVEMENT WITH A MIXED TYPE BINDING SYSTEM BASED ON FLY ASH

The longer service life and lower cost of maintenance are widely recognized as benefits of RCC in comparison to asphalt pavements, as well as the reduced environmental footprint resulting from life cycle assessment measurements. Furthermore, RCC pavements are stronger and resistant to heavy truck circulation. They are recommended for interchange ramps and heavy truck roads in hot climates. The disadvantages of concrete roads are the noise due to the roughness of the surface layer as well as reduced driving comfort. There is, of course, the possibility to add an asphalt topping layer (4-5 cm), but some of the benefits such as reduced thermal emissions and light reflectivity are lost. The initial construction cost of a concrete road pavement is slightly higher than that of an asphaltic pavement, but mixed type binders also contribute to cost reduction.

The strategy for the construction of a RCC road pavement with fly ash-based mixed type binder was developed in the frame of the TEFRODOS Project 2011-2014, funded by the General Secretary of Research and Technology in Greece. The partners were TITAN Cement Industry, the National Technical University of Athens and the Aristotle University of Thessaloniki as coordinator. For the road construction, the following steps were followed:

- <u>Development of the mixed type binder and quality assessment</u>

As it is known, calcareous fly ash constitutes more than 50% of the total European fly ash production and in Greece it is the only fly ash produced, with a current annual output (for 2013) of 8 million tons. Calcareous fly ash is not covered by a relative standard for its use, as in the case of siliceous fly ash [5], however, according to the EN 13282 European Standard for Hydraulic Road Binders [6], it is possible to develop mixed type hydraulic binders. Therefore, a systematic study of the quality of the calcareous fly ash produced at Greek power plants started. The parameters on which the study focused were CaO_{free}, SO_3, Loss on ignition and fineness. It was decided to obtain fly ash from the Agios Demetrios Power Plant without any preselection. Then, the TITAN industry produced various blends of four constituents; fly ash, clinker, pozzolan and limestone filler. For the various blends, measurements were made on fineness, grinding time, water demand, setting time, Le Chatelier volume stability (dilation) and compressive strength at 2, 7 and 28 days.

The characteristics of the constituents of the hydraulic binder are given in Table 1, while the final composition of the mixed type binder, which comprised of 50% calcareous fly ash, 25% clinker, 12.5 % natural pozzolan and 12. % limestone filler and its characteristics are given in Table 2. The grinding to a high Blaine value was considered necessary for the development of 28-day laboratory compressive strength of 40 MPa, so as to have on-site compressive strength of at least 30 MPa. Consequently, the water demand for normal consistency paste of this fly ash-based hydraulic binder was 41.5 % which is considered high, but its volume stability was normal, without any problems.

Table 1. **Chemical analysis and characteristics of the constituents of the hydraulic binder**

Content/ Property	Cement clinker	Calcareous fly ash	Limestone filler	Natural pozzolan
SiO_2 (%)	21,35	34,40	0,20	63,80
Al_2O_3 (%)	5,40	13,60	0,20	18,10
Fe_2O_3 (%)	3,40	6,10	0,05	4,10
CaO (%)	65,75	32,80	55,00	2,80
MgO (%)	1,60	3,80	0,60	1,00
CaO_{free} (%)	1,30	6,40	n/a	n/a
$SiO_{2\text{-reactive}}$ (%)	n/a*	n/a	n/a	35,00
SO_3 (%)	1,20	6,78	0,00	0,00
L.O.I. (%)	0,00	3,26	44,10	3,20
Insoluble residue (%)	0,00	23,80	0,00	82,80

*not measured

- <u>Proportioning of RCC with the calcareous fly ash-based binder and testing properties in fresh and hardened state</u>

The composition of the RCC was based on literature recommendations, as well as on previous experience of the Laboratory of Building Materials of the Aristotle University of Thessaloniki, from the use of calcareous fly ash in RCC dams and pavements [7]. The required strength was fck C25/30 and the design of the RCC mixtures was based on the determination of Vebe density according to ACI 325.10R-95 and relevant standards.

Table 2. **Properties of the produced mixed type hydraulic binder**

Physical properties	
Blaine (cm^2/g)	9550
Fineness (retained at 45 μm)	0,4
Water requirement (%)	41,5
Initial setting time (min)	210
Le Chatelier dilation (mm)	0,0
2-day compressive strength (MPa)	15,9
7-day compressive strength (MPa)	26,3
28-day compressive strength (MPa)	40,1
Chemical properties	
L.O.I. (%)	8,40
SO_3 (%)	3,20
Insoluble residue (%)	26,40
CaO_{free} (%)	4,80
Chemical analysis	
SiO_2 (%)	29,90
Al_2O_3 (%)	12,65
Fe_2O_3 (%)	3,80
CaO (%)	42,90
MgO (%)	2,20

Two crushed limestone aggregate granulometric gradations of maximum grain size 16 mm and 31.5 mm were selected as shown in Figure 1. The quantity of the new hydraulic binder called "tefrocement" ranged from 270 to 300 kg/m^3. The water to cementitious ratio was selected to be ≤ 0.50 when possible and a superplasticizer was also added at different rates. Two series of mixtures were made: Mixtures A with maximum aggregate size 16 mm and Mixtures B with maximum aggregate size 31.5 mm, as shown in Table 3.

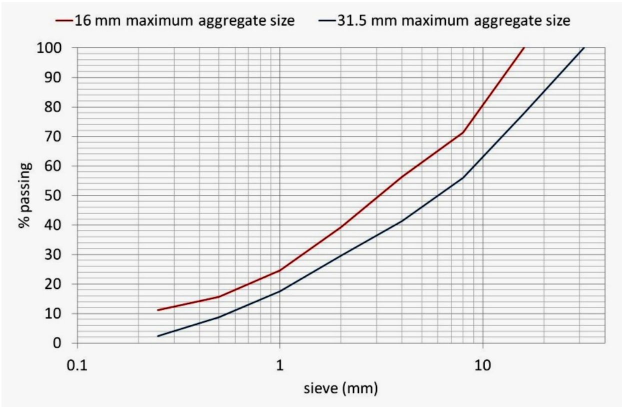

Figure 1. Crushed limestone aggregate gradations for maximum size 16 and 31.5 mm

During the preparation of the trial mixtures at the laboratory, it was observed that the setting was relatively quick and that the Vebe time should be measured also after accounting some time for transportation, so as for the mixture to be adequately workable on site.

Table 3. **Laboratory test mixtures series A and B**

Mixture	A1	A2	A3	A4	B1	B2	B3	B4
Hydraulic Road Binder (kg/m^3)	280	280	280	280	300	270	280	280
Water (kg/m^3)	153	153	196	163	120	135	150	148
Fine aggregate (kg/m^3)	1096	1096	1096	1096	1096	1096	1096	1096
Coarse aggregate (kg/m^3)	897	897	897	897	897	897	897	897
Maximum aggregate size (mm)	16	16	16	16	31,5	31,5	31,5	31,5
superplasticizer (%wt. of binder)	0,0 %	1,0 %	1,0 %	0,0 %	1,0 %	1,0 %	1,0 %	0,5 %
w/cem	0,54	0,54	0,70	0,58	0,40	0,50	0,54	0,53
Vebe time (s)	-	-	20	60	8	9	60	35
Vebe density (kg/m^3)	2427	2396	2428	2410	2396	-	2389	2404
Electrical hammer density (kg/m^3)	2480	2355	2446	2447	-	-	2408	2478
7-d compressive strength (MPa)	33,5	28,3	22,4	32,4	-	22,0	28,6	31,1
28-d compressive strength (MPa)	43,8	35,7	30,9	46,0	35,4	35,3	37,5	42,3

Therefore, the Vebe time was measured at t = 0' and at t = 30' after water addition in a new series of trial mixtures, for which the Vebe density was also compared to that obtained from compaction with an electrical hammer (Table 4). As it can be seen from the results, the values obtained from the two different methods of measuring density were similar.

Table 4. **New series of laboratory test mixtures series A and B, accounting for transport time**

Mixture	A5	A6	B5	B6
Hydraulic Road Binder (kg/m^3)	280	280	280	280
Water (kg/m^3)	148	148	159	148
Fine aggregate (kg/m^3)	1096	1095.8	1095.8	1096
Coarse aggregate (kg/m^3)	912.6	912.6	629.2	629.2
Maximum aggregate size (mm)	16	16	31.5	31.5
superplasticizer (%wt. of binder)	0.0 %	0.5 %	1.0 %	0.0 %
w/cem	0.53	0.53	0.57	0.53
Vebe time (s), t=0'	60	40	12	50
Vebe time (s), t=30'	100	80	30	80
Vebe density (kg/m3), t=0'	2385	2313	2430	2447
Vebe density (kg/m3), t=30'	2420	2410	2415	2400
Electrical hammer density (kg/m^3), t=0'	2474	2505	2466	2490
7-d compressive strength (MPa)	31.4	30.7	25.5	33.7
28-d compressive strength (MPa)	45.6	43.4	37.9	49.3

- Pilot construction of RCC road pavement with a calcareous fly ash-based binder

In Greece there is little experience regarding concrete road pavement construction. In order to establish the details of the construction of a road pavement with RCC by using common equipment for asphaltic beddings, it was decided to proceed in small scale pilot constructions of pavements (30-100 m) on ground of CBR ≥ 18, using the concrete mixtures developed in the laboratory and, in particular, mixtures B4, B5 and B6. The concrete mixture plant was situated at a 30 minute drive distance from the site and transportation was carried out with closed trucks which dropped the concrete into the paver (Figure 2). It was obvious very soon that the continuous feeding of the paver was essential for this RCC with calcareous fly ash because of the quick setting. As indicated in Figure 3, delayed concrete delivery resulted in difficulties in dropping the fresh concrete into the paver. Then, the compaction achieved by the paver and rollers was measured on site with a Humboldt nuclear gauge (Figure 4) and the results are presented in Table 5.

Figure 2. Truck unloading onto paver and RCC laying

Figure 3. Fresh concrete stuck on the truck due to delay in transportation

Figure 4. Fresh concrete density measured with nuclear gauge

Table 5. Nuclear gauge density measurements on freshly bedded RCC (expressed as % of the measured Vebe density)

depth	directly after the paver	after compaction
5 cm	81.8%	90.4%
10 cm	81.2%	91.3%
15 cm	81.0%	90.6%
20 cm	79.7%	89.3%
average total pavement thickness (cm)	-	22.1

It was also found that an effective compaction scenario was to have 3 non-vibrating passes with a 4 ton roller, followed by 2 non-vibrating and 2 vibrating passes with a 10 ton roller (Figure 5). With the available paver, the achieved compaction did not exceed the 80% of the maximum concrete density. Furthermore, the maximum single layer thickness after compaction could not exceed 20 cm. The shrinkage joints were cut every 5.5-6.0 m after the hardening of the pavement to a depth corresponding to 1/4-1/3 of the road thickness (Figure 6). Curing membranes were not used; water spraying was applied in order to keep the road surface dry.

Figure 5. Roller compaction of pavement

Figure 6. Joint cutting

- Long term strength measurement

Two months after the construction of 1 km of RCC road pavement, a survey was carried out and cores were obtained by drilling (Figure 7) for concrete density and strength estimation and the results are shown in Table 6. Frost resistance was also measured by following freeze-thaw cycle testing from -25 °C to 20 °C on the drilled cores. After 50 cycles the drilled cores showed an average 8 % loss of material, while ordinary C20/25 concrete which was used as reference showed an average 5 % loss of material.

Figure 7. Core drilling

Table 6. **Mechanical properties of cores drilled from different areas of the test road (average of 6 cores per area)**

Construction area	1	2	3
pulse velocity u (m/sec)	4625	5022	4713
density ρ (kg/m³)	2295	2394	2345
Compressive strength f_c (MPa)	25.0	32.0	31.8

CONCLUSIONS

Calcareous fly ash was used without any preselection together with cement clinker, natural pozzolan and limestone filler for the production of a mixed type hydraulic binder for concrete road pavements, according to EN 13282. This hydraulic binder consisted of 50 % fly ash, 25 % clinker, 12.5% natural pozzolan and 12.5% limestone filler and may develop 20-30 MPa 28-day strength, which is adequate for a road pavement. The construction of a RCC road with this mixed type binder is feasible and the technical problems that appeared were properly confronted.

The long term strength and resistance were adequate in order to guarantee a long service life. The incorporation of a low cost industrial by-product into a hydraulic binder contributes essentially towards lowering the initial cost of a concrete road, rendering this sustainable alternative also cost-effective.

REFERENCES

1. **Malhotra V. M.** (1999). Making concrete" greener" with fly ash. Concrete International, 21(5).
2. **National** Concrete Pavement Technology Center (2010). "Guide for Roller-Compacted Concrete Pavements". Iowa State University and Portland Cement Association, USA.
3. **ACI 325.10R-95 (2001).** "State-of-the-art report on roller-compacted concrete pavements". ACI Manual of Concrete Practice, ACI, USA.
4. **PCA (2004).** "Guide Specification for Construction of Roller-Compacted Concrete Pavements". Portland Cement Association, Illinois, USA.
5. **Feuerborn H.-J., Müller B. and Walter E.** (2012). "Use of Calcareous Fly Ash in Germany". Proceedings of the International Conference Eurocoalash 2012, Thessaloniki, Greece, September 25-27, 2012.
6. **EN 13282-2 (2013).** Hydraulic road binders – Part 2: Composition, specifications and conformity criteria of normal hardening hydraulic road binders. CEN.
7. **Papayianni I.** (2010). "Use of calcareous ash in civil engineering". Proceedings of the International Conference Eurocoalash 2010, Copenhagen, Denmark, May 27-28, 2010.

I. Papayianni, E. Anastasiou, M. Papachristoforou. Mixed type binding systems. A sustainable alternative for RCC road pavements // Proceedings of the V Conference “Ashes from TPPs: removal, transport, processing, storage”, Moscow, April 24–25, 2014 — M.: MPEI Printing House, 2014. P. 165– 169.