Experience with calcareous fly ash in road construction -case study Greece

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Fly ash-Greece

- 8 million tons current annual output
- Calcareous fly ash
  - High content in lime and sulfates
  - Exhibits self hardening properties apart from pozzolanic ones

Research work

Utilization of fly ash in road construction

- Stabilization of soils
- Construction of RCC road pavement with fly ash-based binder
- Construction of sub-base with fly ash-based binder

Soil stabilization

Stabilization can be used in areas with weak soil deposit for:

- sub bases
- foundations
- embankments

Soil stabilization means:

- increase load bearing capacity
- reduce swelling problems
- enhance impermeability

can be achieved with a variety of additives including:

- Lime
- Portland cement
- Fly ash or other by-products

Soil stabilization-Experimental program

- Soil: Soil1 and Soil2
- Fly ash: FA1, FA2, FA3 and FA4

	Power plant	CaO_{free} (%)	SO_3 (%)	Fineness R_{45} (%)	Apparent specific density (gr/cm^3)
FA1	Amynteo	9.08	6.60	50.53	2.30
FA2	Kardia	7.93	8.09	37.50	2.48
FA3	Ptole/da	3.69	3.85	50.00	2.40
FA4	Amynteo	11.20	6.60	38.50	2.39

Soil stabilization-Experimental program

- Soils
  - Mechanical an physical properties
    - Atterberg Limits
    - optimum moisture content, max density (modified Proctor method)
    - Californian Bearing Ratio (CBR)
- Soil-fly ash mixtures (fly ash addition rate 0, 10, 15, 20 and 100% by mass)
  - Proctor density, optimum moisture content
  - CBR
  - Swelling deformation

Soil stabilization-Experimental program

Groups of mixtures			
Soil1-FA1	**Soil1-FA2**	**Soil2-FA3**	**Soil2-FA4**
0%FA1	0%FA2	0%FA3	0%FA4
+10%FA1	+10%FA2	+9%FA3	+9%FA4
+15%FA1	+15%FA2	+13%FA3	+13%FA4
+20%FA1	+20%FA2	+17%FA3	+17%FA4
100%FA1	100%FA2	100%FA3	100%FA4

Soil stabilization-Experimental program

Atterberg Limits	**Soil 1** Value (%)	**Soil 2** Value (%)
Liquid limit WL	34.00	34.87
Plastic limit WP	17.00	18.15
Plasticity Index P1	17.00	16.72
Mean value of natural moisture w (%)	2.88	2.68

Classification of soils according to Unified Soil Classification System (USCS):

- Soil 1 as CL (inorganic argillaceous of low plasticity)
- Soil 2 as SW (well-graded gravel and sand).

Soil stabilization-Experimental program

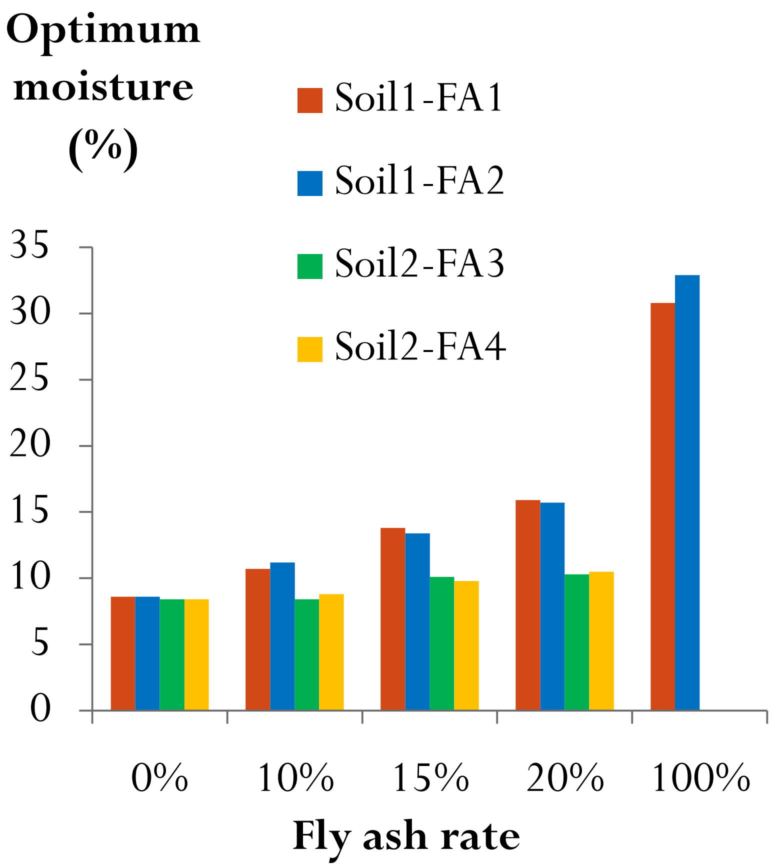
Modified Proctor method:

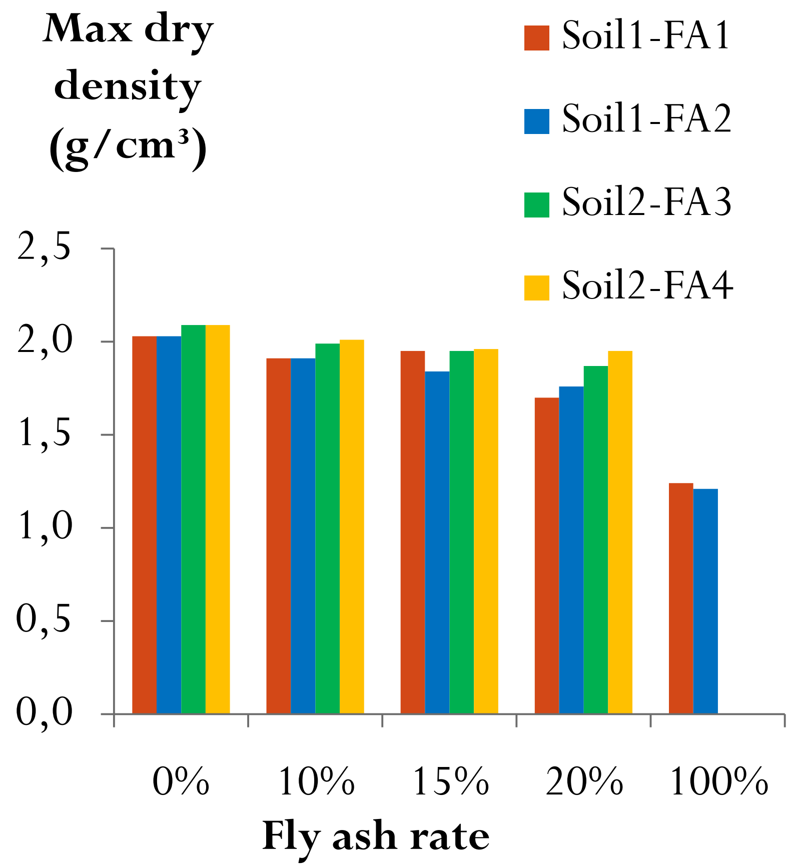
	Soil 1	Soil 2
Max dry density (kg/m^{3})	2030	2095
Optimum moisture (%)	8.6	8.4

Soil stabilization-Experimental program

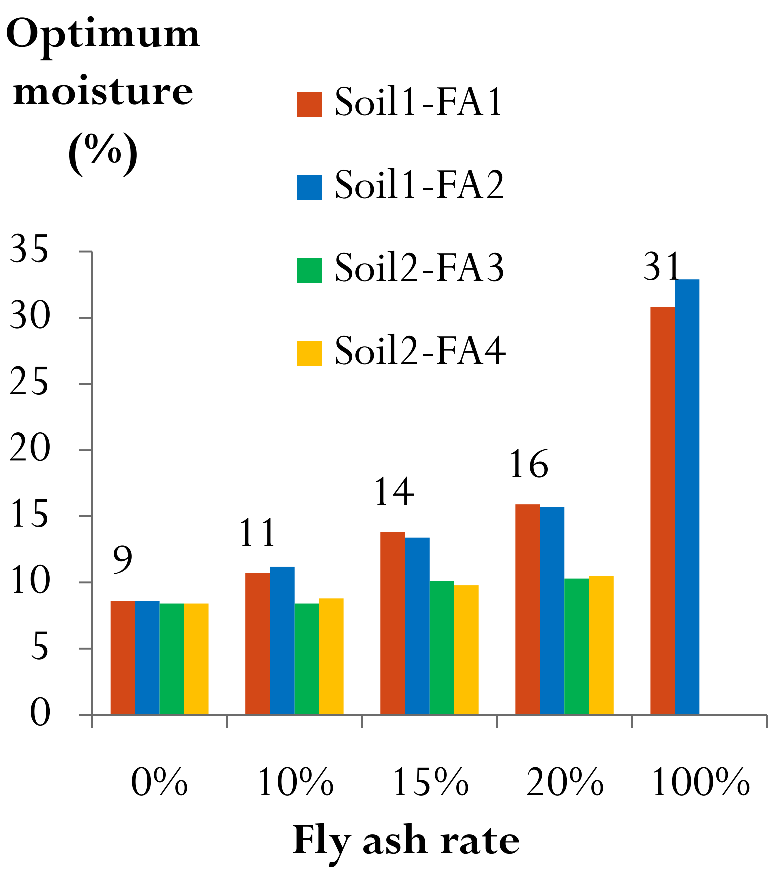
	Soil1			Soil2		
No of Knocks	10	30	65	10	30	65
Dry density (kg/m3)	1818	1875	2030	1791	2021	2097
CBR (%)	4.0	18.5	27.0	2.9	9.7	23.2
Swelling (%)	1	0	0	1	0	0
CBR (%)		**18.5**			**9.7**	

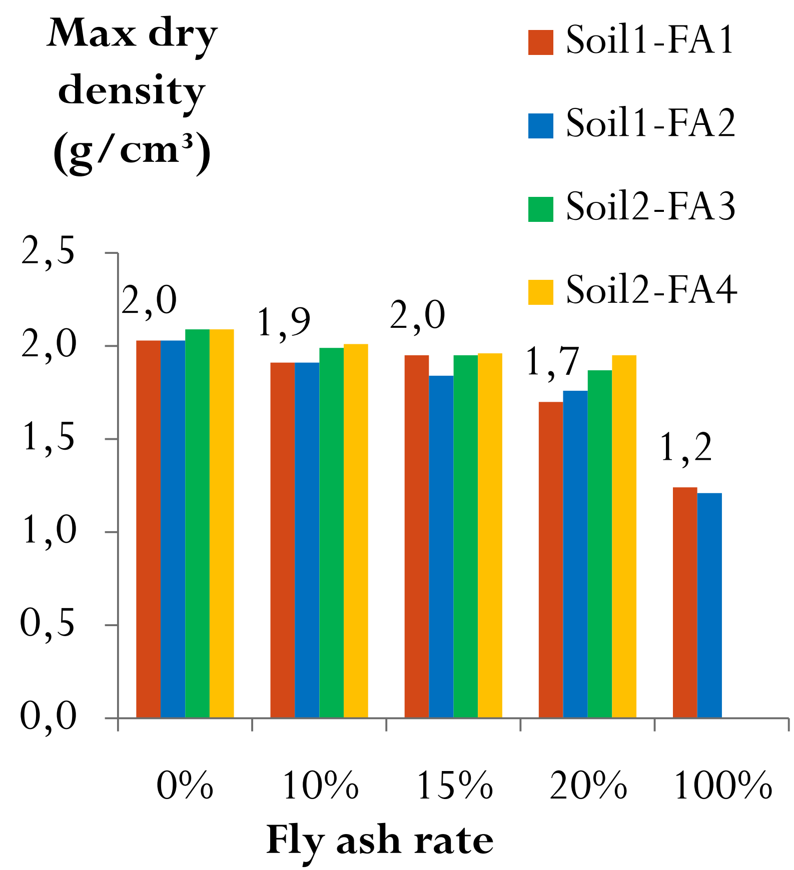
Soil stabilization-Experimental program





Soil stabilization-Experimental program

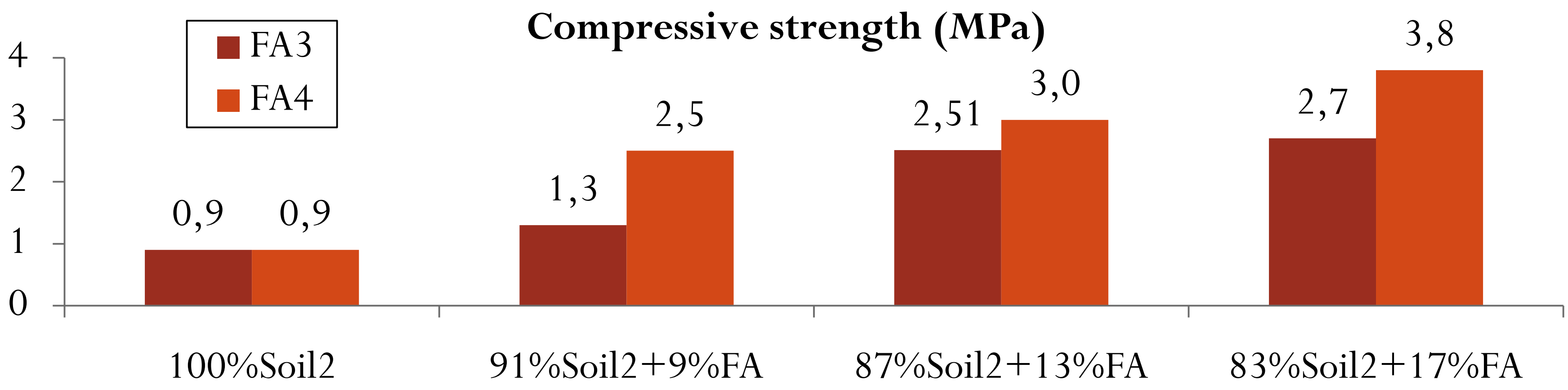


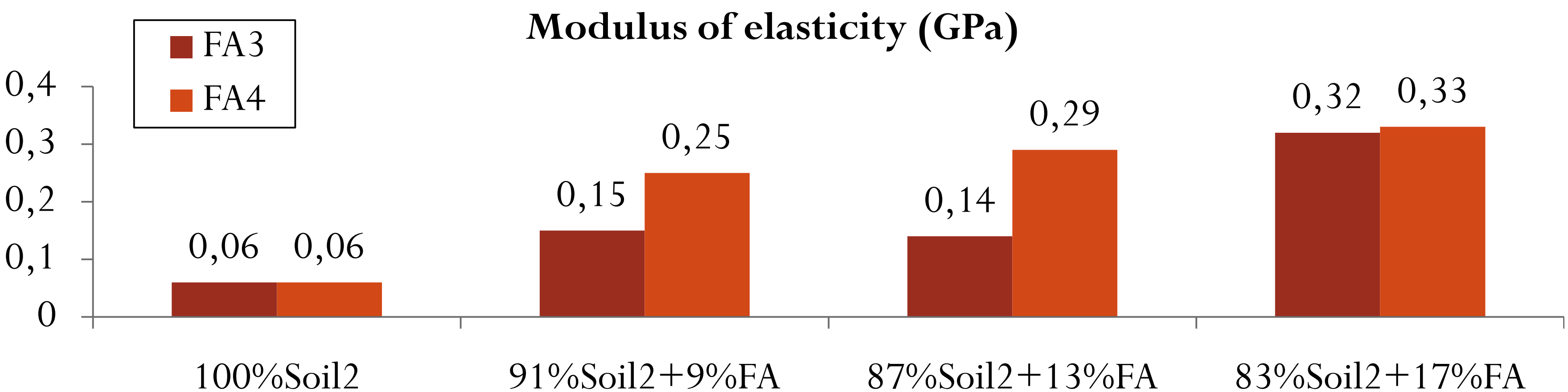


Soil stabilization-Experimental program

Soil1+FA1	100%Soil1	90%Soil1 10%FA1	85%Soil1 15%FA1	80%Soil1 20%FA1	100%FA1
CBR %	18.5	28.0	127.0	97.0	195.0
Swelling			from 0-3%		
Soil1+FA2	**100%Soil1**	**90%Soil1 10%FA2**	**85%Soil1 15%FA2**	**80%Soil1 20%FA2**	**100%FA2**
CBR %	18.5	167.0	148.0	144.0	227.0
Swelling			from 0-5%		
Soil2+FA3	**100%Soil2**	**91%Soil2 9%FA3**	**87%Soil2 13%FA3**	**83%Soil2 17%FA3**	**100%FA3**
CBR %	9.7	27.0	41.0	54.0	-
Swelling			from 0-1%		
Soil2+FA4	**100%Soil2**	**91%Soil2 9%FA4**	**87%Soil2 13%FA4**	**83%Soil2 17%FA4**	**100%FA4**
CBR %	9.7	152.0	156.0	181.0	-
Swelling			from 0-1%		

Soil stabilization-Experimental program





The construction of a RCC road pavement and sub-base with a fly ash-based binder

Stakeholders:

- Aristotle University of Thessaloniki (responsible for research and consultancy)
- National Technical University of Athens
- TITAN Cement Industry
- EGNATIA ODOS S.A.
- TERNA Construction Company

Project:

- TEFRODOS 2011-2014

Funds:

- General Secretary of Research and Technology, Greece

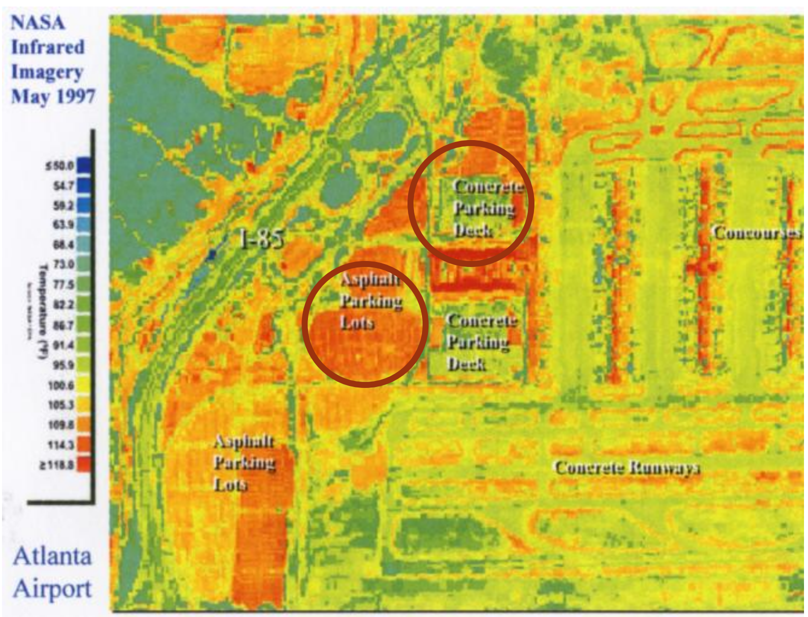
Background-Binders

- Portland cement is an excellent high-strength binder which predominates in construction, but is also an energy consuming, high-cost material of low ecological profile
- Under the pressure of reality:
  - Climatic changes and catastrophes
  - Global economic depression
  - Need of longer service life for constructions
- There is an urgency to develop alternative binding systems

The construction of a RCC road pavement with a fly ash-based binding system

- In Greece, only asphaltic concrete is used for road pavements
- There is no tradition in bedding concrete road pavement
- The RCC pavement alternative seems to be the most feasible solution
- The main advantages for such a solution are:
  - Longer service life and lower cost of maintenance
  - Reduced environmental footprint
  - RCC is stronger and resistant to heavy truck circulation
  - Thermal emissions are redacted

The construction of a RCC road pavement with a fly ash-based binding system



Infrared photograph of the Atlanta Hatfield Airport (property of NASA) where asphalt parking lots develop higher temperature compared to concrete parking lots

Steps

RCC construction

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

Sub-base construction

- Proctor-CBR tests of soil-fly ash based binder mixtures
- Pilot construction
- Mechanical properties

Development of the mixed type binder and quality assessment

- Aim: 28-d compressive strength of 40 MPa, so as to have on site at least 30 MPa
- Materials (% by mass)
  - Calcareous fly ash 50%
  - Clinker 25%
  - Natural pozzolan 12.5%
  - Limestone filler 12.5%

→Blended mixed type binder "Tefrocement"
Testing according to EN 13282 for Hydraulic Road Binders

- Test measurements:
  - Fineness
  - Grinding time
  - Water demand
  - Setting time
  - Le Chatelier volume stability
  - Compressive strength at 2, 7 and 28 days

Characteristics of the constituents of the hydraulic binder developed

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

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

Proportioning RCC with fly ash-based hydraulic binder "Tefrocement"

- Required strength: 30 MPa
- Maximum Vebe density (according to ACI 325.10R-95) with Vebe time: 20-40s
- Available aggregates: Crushed limestone of maximum size 31.5 mm or 16 mm
- "Tefrocement" quantity: ≤ 300 kg/m^3
- Water/cementitious ratio: ~ 0.50

Trial mixes 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
Max. 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	0.60	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
7-d compr. strength (MPa)	33.5	28.3	22.4	32.4	-	22.0	28.6	31.1
28-d compr. strength (MPa)	43.8	35.7	30.9	46.0	35.4	35.3	37.5	42.3

- Decision to use 280 kg/m^3 “Tefrocement”

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/m^3), t=0'	2385	2313	2430	2447
Vebe density (kg/m^3), 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-parameters

- Ground layer with CBR ≥ 18
- Concrete plant at 30 minutes driving distance
- Continuous feeding of the paver
- Compaction achieved by rollers
- Compaction was measured with Humboldt nuclear gauge

Truck loading

Truck unloading onto paver

Difficulty unloading truck due to delay in transportation

Laying RCC

Roller compaction of pavement

Fresh concrete density measured with nuclear gauge

Effective compaction scenario

- 3 non vibrating passes with a 4 ton roller
- 2 vibrating passes with a 10 ton roller
- Maximum single layer thickness achieved: 20 cm

Achieved compaction

- Only with the paver, the compaction achieved was 80%

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%

Joints

- Shrinkage joints: cut every 5.5-6.0 m after hardening, to a depth corresponding to 1/4 - 1/3 of the road thickness

Survey of concrete pavement 2 months after construction

- Core drilling and testing
  - Mechanical properties
  - Freeze-thaw resistance (-25°C to +20°C)

Survey of concrete pavement 2 months after construction

- Mechanical properties of drilled cores

Construction area (average of 6)	1	2	3
pulse velocity u (m/s)	4625	5022	4713
density ρ (kg/m^3)	2295	2394	2345
Compressive strength f_c (MPa)	25.0	32.0	31.8

Sub-base pilot construction with fly ash based binder

Crushed limestone 0-150 mm

- 5 and
- 10 % b.w. addition of mixed type binder

Mixture	Optimum moisture content (%)	Max. Dry density (g/cm^3)	CBR (%)
5% binder	6,2	2,335	30
10 % binder	6,4	2,262	55

Sub-base pilot construction with fly ash based binder

Binder addition

Sub-base pilot construction with fly ash based binder

Mixing and loading

Sub-base pilot construction with fly ash based binder

Placing

Sub-base pilot construction with fly ash based binder

Water addition and mixing

Sub-base pilot construction with fly ash based binder

Compaction and final form

Sub-base pilot construction with fly ash based binder

Compaction level

	Depth (cm)	Compaction Rate (%)	Compressive strength (MPa)
	5	96,1	
5% Binder	10	97,1	7,1
	15	96,6	
	5	96,6	
10% Binder	10	98,6	13,4
	15	101,5	

Sub-base pilot construction with fly ash based binder

Properties of drilled cores

	Average layer thickness (cm)	Density (g/cm³)	UPV (m/s)	Compressive strength (MPa)	Modulus of Elasticity (GPa)	Spliting strength (MPa)
5% Binder	14,3	2,32	3164	7,2	0,59	0,71
10% Binder	9,8	2,24	3297	7,51	1,22	1,43

Conclusions-Soil stabilization

Addition of fly ash in soils:

- Mechanical properties are significantly increased

Increase of mechanical properties of Soil-FA mixtures compared to net soil				
	FA1	**FA2**	**FA3**	**FA4**
CaO_{free}	**9%**	**8%**	**4%**	**11%**
CBR	**6.86** times higher	**8** times higher	**5.56** times higher	**18** times higher
Compressive strength	-	-	**3** times higher	**4.2** times higher
Modulus of Elasticity	-	-	**5.3** times higher	**5.5** times higher

- No swelling problems appeared
- Rich in lime fly ashes exhibited higher strength development
- Optimum moisture is increased and maximum dry density is reduced.

Conclusions-Construction of RCC road pavement and sub-base with fly ash-based binder

- The construction of a RCC road with this mixed type binder is feasible
- The technical problems that appeared were properly confronted
- The long term strength and resistance were adequate in order to guarantee a long service life
- Cost reduction
- Successful implementation in sub-base with ordinary equipment
- Layers of lower thickness can be constructed

Thank you for your attention!