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Production and characterization of concrete paving blocks containing electric arc furnace slag as a substitute for aggregates

N. Dimitrioglou, P.E. Tsakiridis, N.S. Katsiotis, M.S. Katsiotis, P. Perdikis, M. Beazi

Concrete Paving Blocks (CPB)

- Usually industrial products of pre-fabricated unarmed concrete, having various dimensions and special morphology
- A standard surface in Europe, suitable for a range of applications
- Raw materials required for their manufacture are Portland cement and different types of aggregates

Electric Arc Furnace Slag (EAFS)

- In the present study EAFS was used as a substitute for limestone aggregates in the production of H-shaped **concrete paving blocks (CPB)**.
- **EAFS** is a byproduct obtained from smelting of laterite ore in an electric arc furnace at a high temperature with the presence of a reducing agent, for the production of ferronickel alloys.
- The largest amount of the produced slag is temporary disposed in areas closed to the metallurgical plant.
- **Byproducts** has been encouraged, not only due to the need for resources conservation, but, regarding industrial wastes, minimization of soil/water contamination and disposal cost as well.

CPB Production in pilot scale

- **Materials**
  - CEM I 52.5 Ordinary Portland Cement
  - EAFS (LARCO)
  - Limestone (LS)
  - Superplasticizer
- **Mixtures**
  - Three compositions: a reference (CPBRef), and two others containing 10 wt% (CPB10) and 20 wt% (CPB20) aggregates replacement by FNS.
  - For each composition approximately 1000 blocks.

Mixtures Proportions

Code	*CEM I52.5 (kg/m³)*	*w/c*	*LS (kg/m³)*	*EAFS (kg/m³)*	*Superplasticizer (kg/m³)*
CPB_{Ref}	175	0.45	1569	-	1.0
CPB_{10}	175	0.45	1412	157	1.0
CPB_{20}	175	0.45	1255	314	1.0

CPB Characterization

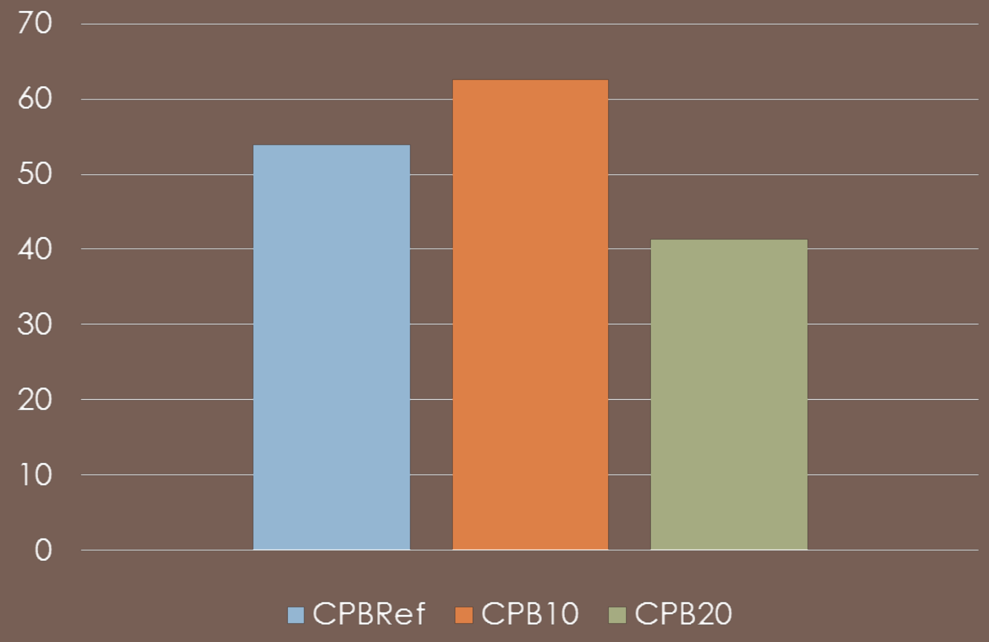
- compressive and tensile/splitting strength
- water absorption and abrasion resistance
- spectral reflectance and thermal conductivity
- morphological characteristics and microstructure

Compressive Strength

- The compressive strength of the reference block is approximately 15% lower than that of the CPB10 mixture.
- The addition of EAFS and the LS replacement acted beneficial in the mechanical properties of the final product, a fact that was attributed to the pozzolanic nature of the slag.
- In case of 20 wt% substitution a decrease of 30% was observed, a fact that was mainly attributed to lower intrinsic strength of the EAFS aggregates.

Compressive Strengths of CPB different mixtures

Mixture	*Weight (kg)*	*Density (kg/m^3)*	*Rate (kN/s)*	*Load (kN)*	*Stress (MPa)*	*Compr. Strength (MPa)*
CPB_{Ref}	2.631	2192.5	13.5	1023	51.1	53.9
	2.627	2189.2	13.5	1072	53.6	
	2.715	2262.5	13.5	1138	56.9	
CPB_{10}	2.737	2280.8	13.5	1299	64.9	62.5
	2.566	2138.3	13.5	1203	60.3	
	2.680	2233.3	13.5	1244	62.2	
CPB_{20}	2.585	2154.2	13.5	787	39.4	41.4
	2.560	2133.3	13.5	736	36.8	
	2.698	2248.3	13.5	962	48.1	

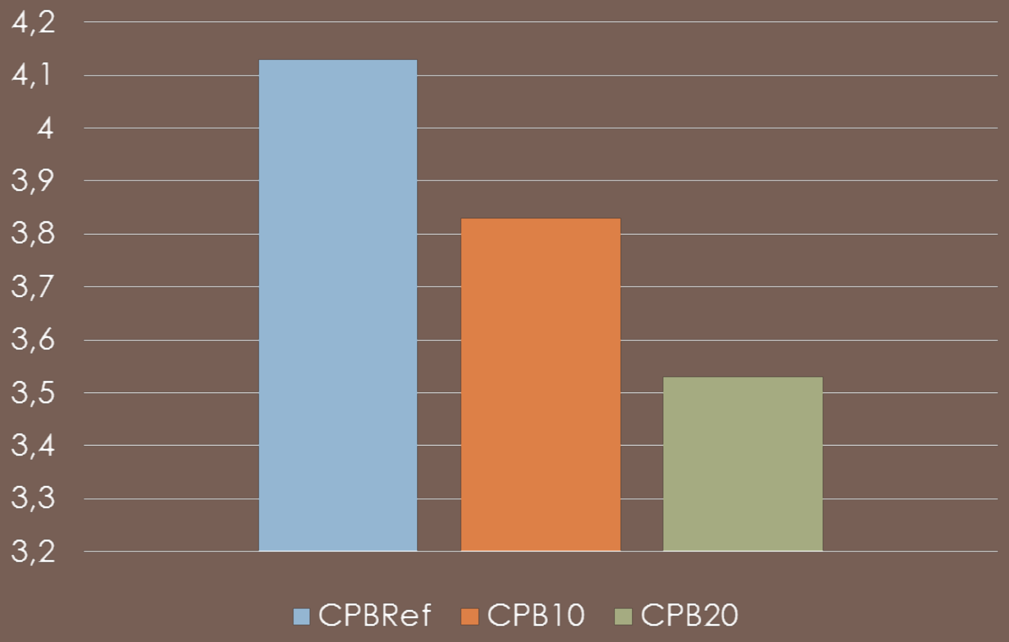


Splitting Tensile Strength

- In case of using 10 wt% EAFS a decrease of 7.28% in the splitting tensile strength was observed, whereas in case of CPB20 the corresponding value reached at 17%, as compared with the control sample.
- The replacement of the LS aggregates with the more reactive EAFS, led to the improvement of the interfacial transition zone, as the amount of hydration products formed during the later hydration stages were increased due to the pozzolanic nature of the slag.

Splitting Tensile Strengths of CPB different mixtures

Mixture	*Load (N/mm)*	*Splitting Strength (MPa)*	*Average (MPa)*
	459	4.1	
CPB_{Ref}	479	4.3	4.13
	442	4.0	
	460	4.2	
CPB_{10}	414	3.7	3.83
	403	3.6	
	394	3.6	
CPB_{20}	397	3.6	3.53
	379	3.4	

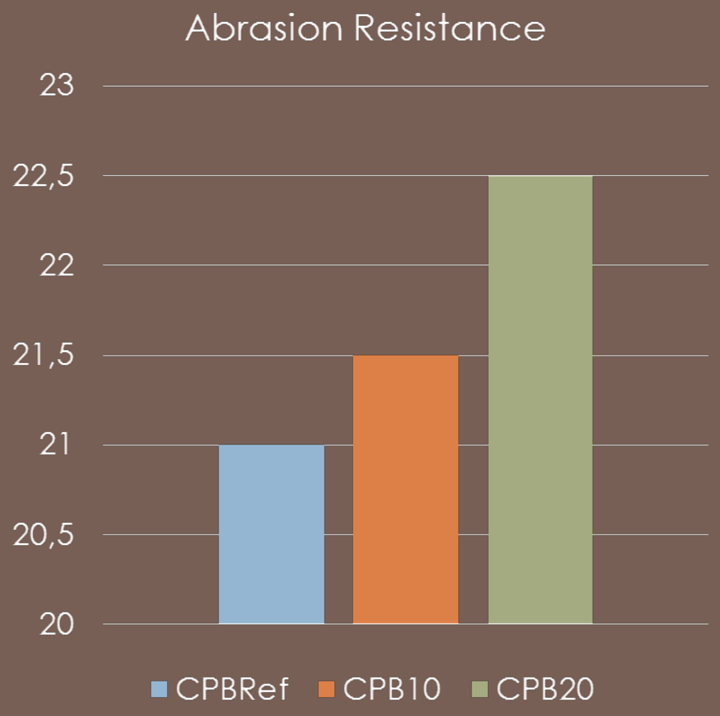


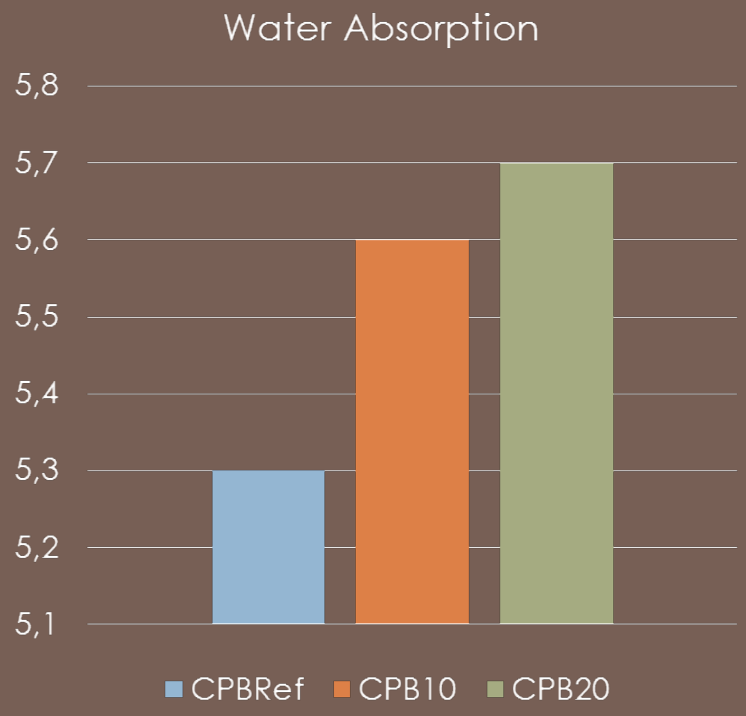
Abrasion Resistance and Water absorption

- An average value of 7% reduction was obtained for the paving blocks with 20% LS aggregates replacement, as the ability of concrete to withstand abrasion improves with the increase in the concrete strength
- The water absorption is mainly related to the pore distribution inside the cement matrix, whereas the influence of aggregate is relatively small and do not contribute to the total blocks water absorption. Thus, the obtained values are similar in all cases.

Abrasion Resistance and Water Absorption of CPB different mixtures

Mixture	*Abrasion Resistance (mm)*	*Water Absorption*	
		wt%	*Average*
CPB_{Ref}	21.0	4.9 5.5 5.5	5.3
CPB_{10}	21.5	5.7 5.6 5.5	5.6
CPB_{20}	22.5	5.8 5.6 5.6	5.7





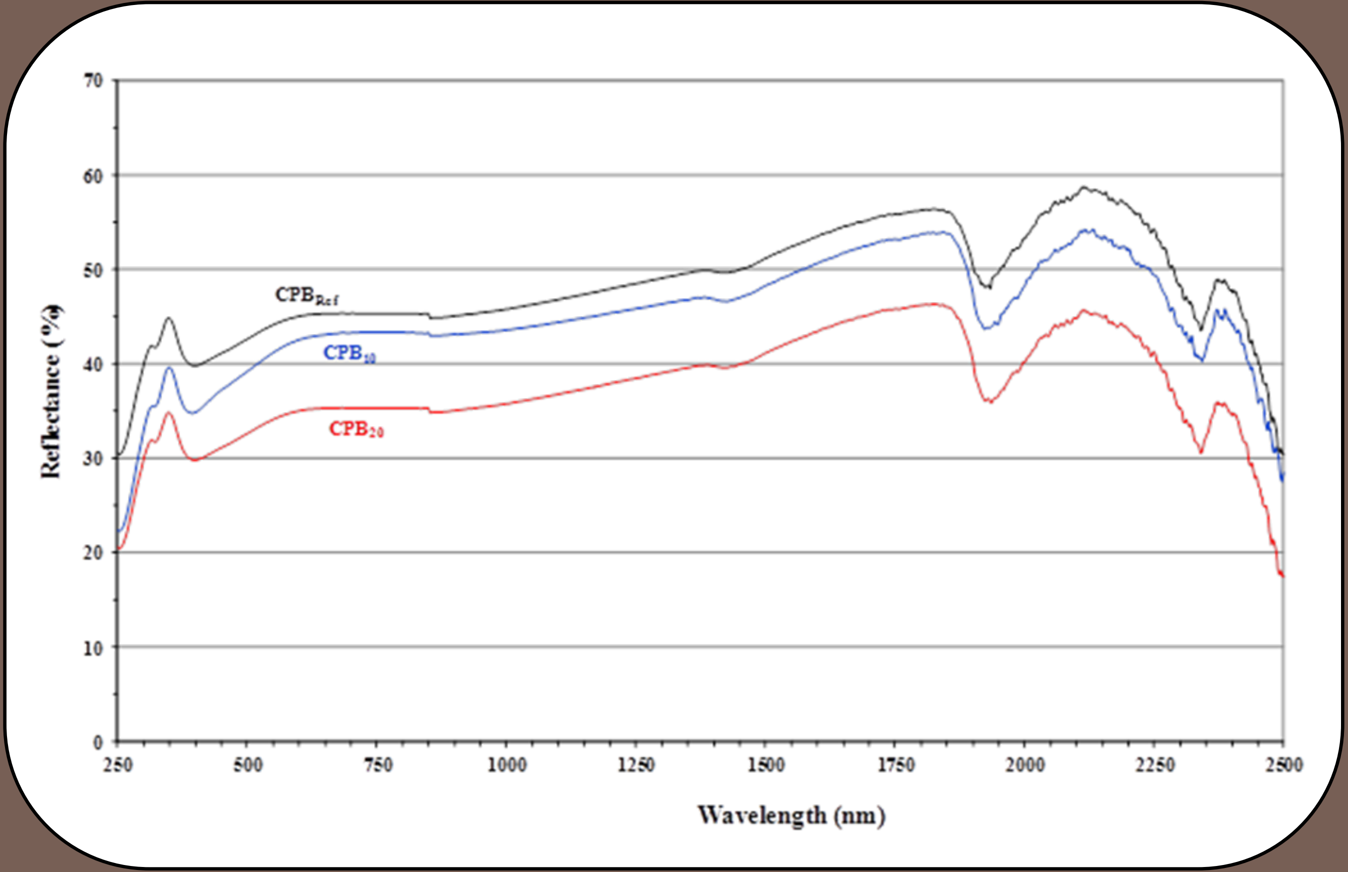
Solar Reflectance and Thermal Conductivity

- The reduction of the solar reflectance was mainly attributed to the darker shade of the slag used, but also to the consumption of Ca(OH)2 produced, due to the pozzolanic reaction
- The reduction of the thermal conductivity should be attributed to the nature of the aggregates used, as they can cause nearly twice a decrease in thermal conductivity of concrete, mainly due their degree of crystallization

Results of solar reflectance and values

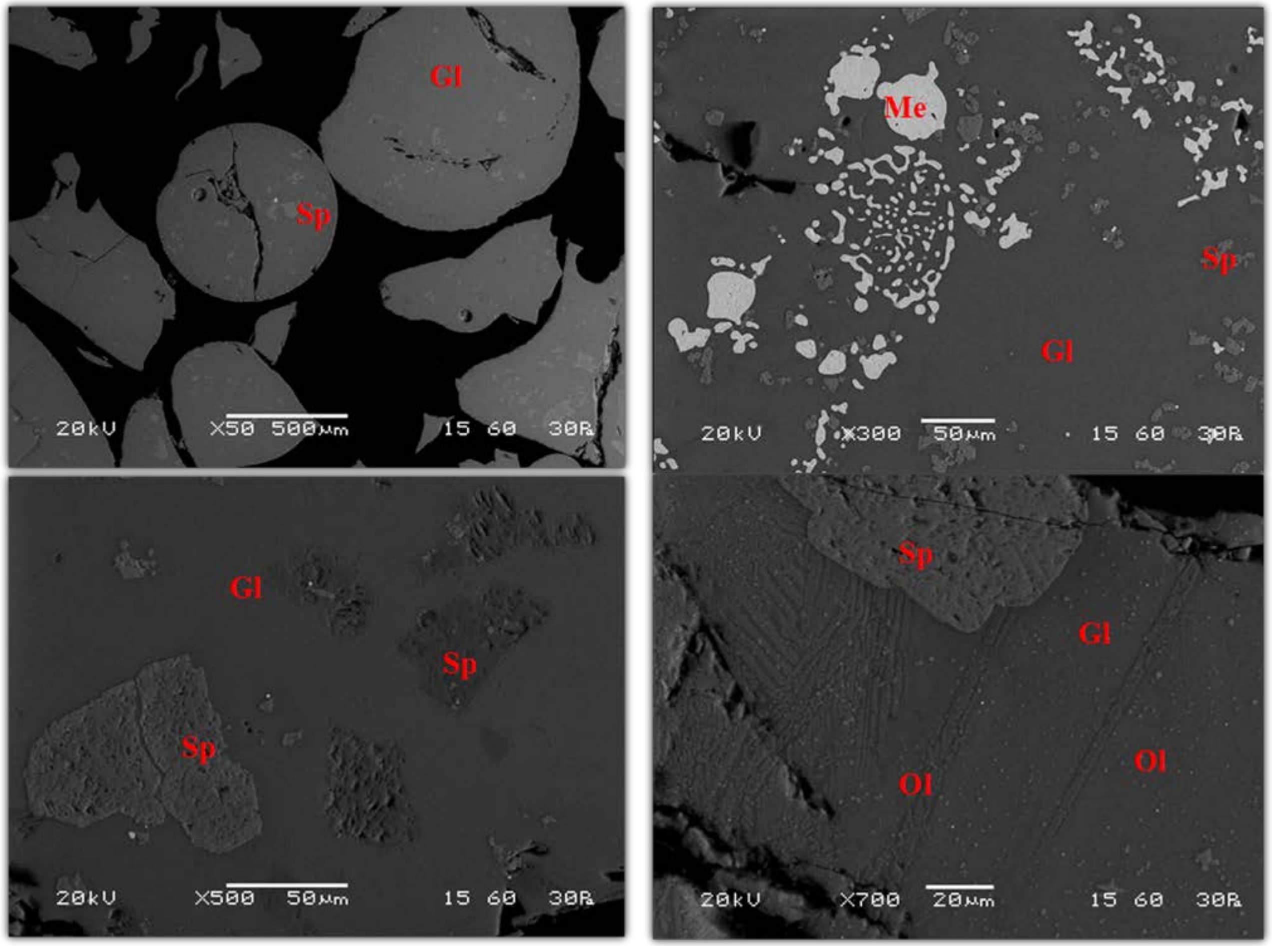
Code	*Reflectance (%)*				*Thermal Conductivity (W/mK)*
	Total 250-2500 nm	*NIR 700 -200 nm*	*UV 280-400 nm*	*Vis 380-780 nm*	
CPB_{Ref}	45.38	48.32	44.88	43.14	1.22
CPB_{10}	42.75	45.15	36.65	40.87	1.13
CPB_{20}	35.45	37.38	31.95	33.76	0.95

Reflectance spectra of the produced concrete paving blocks



SEM Analysis

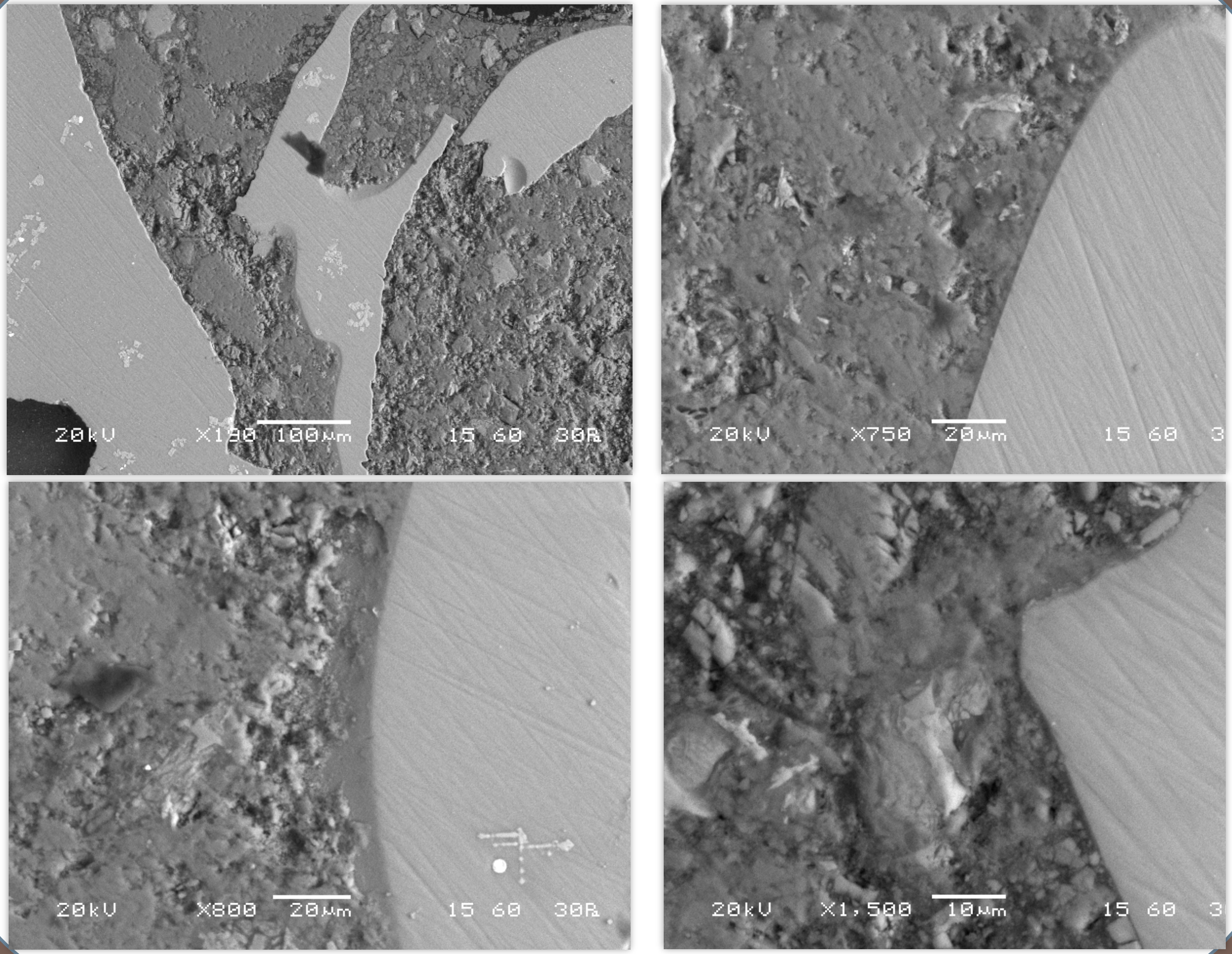
- Presence of a diffuse wide band from the glassy phase. The glass phase appears colourless and is chemically heterogeneous, as it is formed mostly by silicon, iron, aluminium and magnesium
- The spinel phase [$(Fe^{2+},Mg)(Fe^{3+},Al,Cr)_2O_4$] was the only crystalline mineralogical phase that was detected in the slag
- The ferronickel slag still contains small amounts of metallic particles with various complicated forms



Backscattered electron micrographs of the as received FeNi slag polished sections. Fine to coarse-sized euhedral crystals of spinel (Sp) embedded in glassy matrix (Gl). Parallel growths of columnar elongated olivine-group crystals (Ol) and drop-like metallic particles composed of FeNi (Me)

CPB10 Microstructure

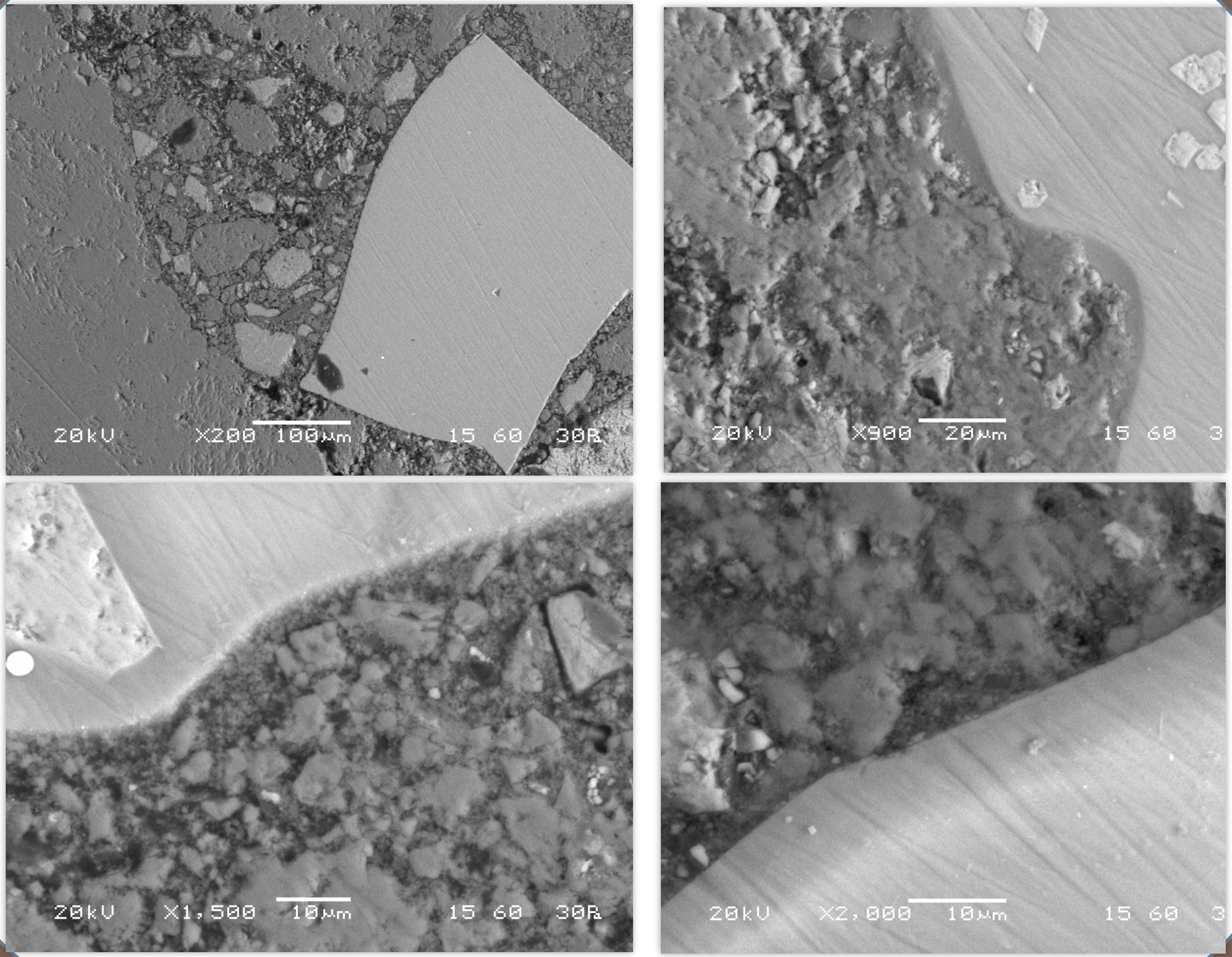
- Unreacted anhydrous cement grains with an external rim of inner calcium silicate hydrated products, outer CSH, which is the hydration product that fills the matrix, and slag particles surrounded by secondary CSH gel
- CSH near the cement grains is much denser and stronger, while the density of the CSH is more uniform



Backscattered electron micrographs of CPB_{10} after 28 days of curing

CPB20 Microstructure

- Partially hydrated slag particles were detected, showing a microstructure with a dense rim of hydration products
- The volume of hydration products in the aggregate-paste interface zone has been increased, thus improving the cohesion between the cementitious matrix and FNS.



Backscattered electron micrographs of CPB_{20} after 28 days of curing

Conclusions

- The **compressive strength** of the reference block was approximately 15% lower (53.9 MPa) than that of the CPB10 mixture (62.5 MPa). On the contrary, in case of 20 wt% substitution (41.4 MPa) a decrease of 30% was observed.
- Regarding **splitting tensile strength**, the addition of 10 wt% EAFS led to a decrease of 7.28%, whereas the corresponding of the CPB20 reached at 17%.
- The use of EAFS as a partial replacement of LS aggregates did not negatively affect the **abrasion resistance** (AR) and the **water absorption** (WA) of the produced blocks and all syntheses satisfied the requirements (AR<23 mm and WA<6 wt%) of the standard BS EN 1338.
- The **solar reflectance** of the paving blocks with 10wt% substitution was slightly decreased (5.75%), a fact that was attributed to the darker shade of the EAFS, but also to the partial consumption of $Ca(OH)_2$ due to pozzolanic reaction. However, a significant drop has been noticed in case of 20 wt% substitution (28%).
- Both syntheses with EAFS addition presented better **thermal insulation properties**, mainly because of the amorphous nature of the slag.
- The EAFS combination with LS aggregates, **presented a potential to be used in the production of concrete paving block, satisfying the requirements as per standard EN 1338.**

Thank you

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nikosdimitri@mail.ntua.gr | +30 210 7723288 | National Technical University of Athens