SDIMI2013
30 June - 3 July

SUSTAINABLE DEVELOPMENT IN THE MINERALS INDUSTRY
6th International Conference
Milos Island, Greece

Sustainable use of resources into fired clay bricks

P. Samaras[1], V. Karayannis[2], X. Spiliotis[3], K. Ntampegliotis[3], G. Papapolymerou[3]

[1]Alexander Technological Education Institution of Thessaloniki, Thessaloniki, Greece

[2]Technological Education Institution of West Macedonia, Kozani, Greece

[3]Technological Education Institution of Thessalia, Larissa, Greece

Introduction

- Fly ashes:
  Produced in **huge amounts** from lignite/coal combustion in thermal power plants
- Utilization of fly ash in construction applications:
  - Expected to increase
  - Noticeable research focuses on **ash addition into clayey mixtures**
  for manufacturing conventional fired bricks and tiles and other construction products
- Electric arc furnace technology:
  Increasing rates in the steel-making industry over the last decades
  resulting in the production of **large quantities of solid residues**,
  including **steel dust (electric arc furnace dust)**, one of the major by-products
- Recycling of steel dust:
  - Also **very important**
  - Incorporation of steel dust in ceramic clay bodies is being examined
- Recently, the synergy of various mixtures of several industrial solid wastes
  containing silica, alumina and lime as the predominant oxides
  towards the development of **value-added construction materials**,
  including ceramics, glass-ceramics & cement-based materials, is under consideration
- Limited data are reported regarding **synergistic usage** of fly ash with steel-industry powder residues into fired clay bricks
- Appropriate mixture compositions of these by-products
  can be **attractive starting materials** for ceramics development

Current study

- Raw materials:

  Innovative synergistic utilization
  of **lignite fly ash** along with **steel-making dust** into clay-based bricks

  - ▸ These by-products contain **several valuable oxides**
    → they can be examined as secondary materials in ceramics manufacturing
  - ▸ **Composition differences** between them provide a stimulating research field

- Methods:

  Plastic **extrusion** and **firing** for fabrication of rectangular brick specimens

- Characterization

  \- **Microstructure**: SEM-EDX analysis

  \- **Properties**:
  * Total volume shrinkage
  * Water absorption capacity & Open porosity
  * Thermal conductivity
  * Bending strength

- Aims:

  \- **Synergistic valorization** of these industrial by-products
  to partially alleviate **waste management** problems

  \- **Substitution** for **huge quantities** of **clayey minerals** that are demanded
  for the production of considerable amounts of fired bricks

  \- The **low cost** of these industrial residues and even **possible energy savings**
  upon clay/waste mixtures firing should also be taken into consideration

Raw materials

Base raw materials:

Clays typically used by the ceramic industry

Industrial powdery by-products:

- Fly ash from lignite power station (FA)

  High-Ca (CaO>30%wt.)

  → Class-C FA (ASTM)

- Steel-making dust (EAFD)

  - Solid by-product from gas treatment of steel-industry electric arc furnace

  - Main oxides: **FeO** and **ZnO** (**over 50 wt. %** of the dust)

Chemical composition (%wt.) of FA

Composition	(%wt.)
SiO_2	30.16
Fe_2O_3	5.10
Al_2O_3	14.93
CaO	34.99
MgO	2.69
SO_3	6.28
Na_2O	1.01
K_2O	0.40

Main components (%wt.) of EAFD

Component	(%wt.)
FeO	37.7
ZnO	22.0
PbO	12.0
CaO	7.7
Na_2O	5.1
SiO_2	3.7
MnO	3.2
MgO	2.2
K_2O	2.1
SO_3	1.4
Cl	1.3
Al_2O_3	0.7

Preparation of specimens: Pilot-plant simulation of industrial brick manufacturing

Extrusion of specimens

Formation of plastic mass

As-extruded green specimens

Sintering – Final consolidation of the extruded specimens

a) Drying in air for 24h
b) Drying in oven at 105°C for 48h
c) Firing in programmable furnace up to 850, 950, 1050, 1150 °C

Testing of specimens

- **Total Volume Shrinkage**

$\mathbf{V_s} = 100(V_w - V_f)/V_w$

V_s: specimen volume shrinkage (%)
V_w: wet specimen volume
V_f: fired specimen volume

- **Thermal conductivity coefficient (k)**

Testing at 25°C using the "guarded heat flow meter" method (Anter Unitherm Model 2022)

- **Water Absorption Capacity & Open Porosity**

- Immersion in water (25-30°C) for 24h
- **WA (%)** = $100(W_{wet} - W_{dry})/W_{dry}$
- **OP (%)** = $100(W_{wet} - W_{dry})/\rho V$

W: specimen weight
V: specimen volume
ρ: water density

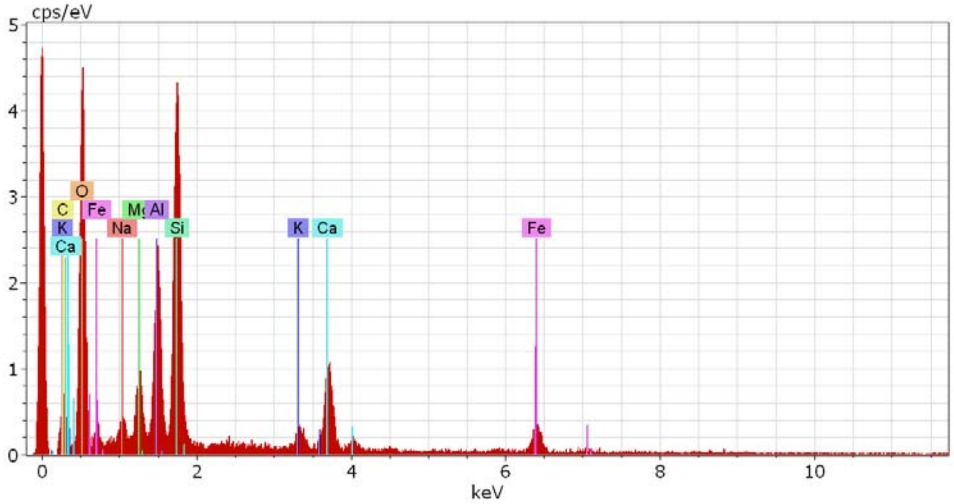
- **3-point Bending Strength**

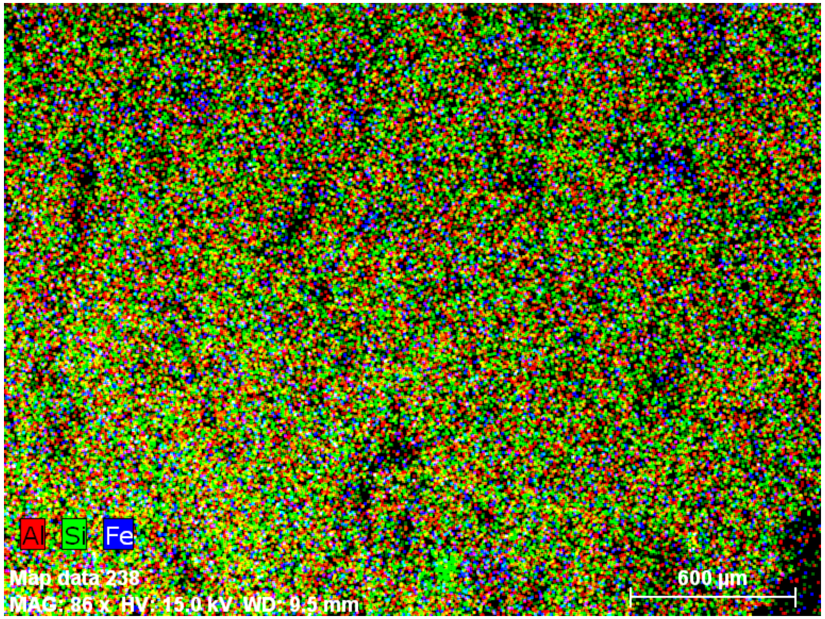
- **30** test specimens
- **Modulus of Rupture** (M.O.R.)**:**

M.O.R. = $(3PL)/(2BW^2)$

P: fracture load (MN),
L: half of the span between the bend ring supports (m)
B: specimen width (m)
W: specimen height (thickness) (m)

Chemical elemental analysis by SEM-EDX

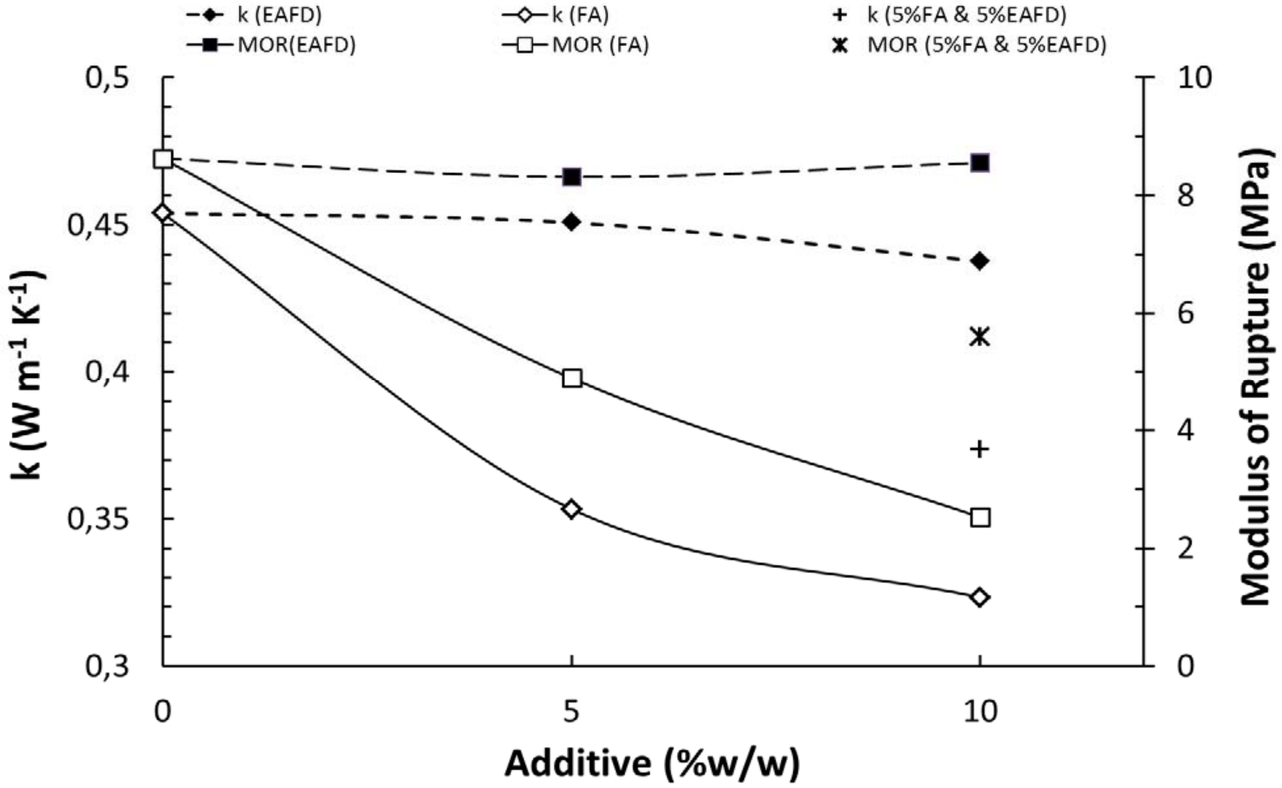




Element mapping of **5+5(FA+EAFD)%wt.** content clay bricks fired at **1050ºC**

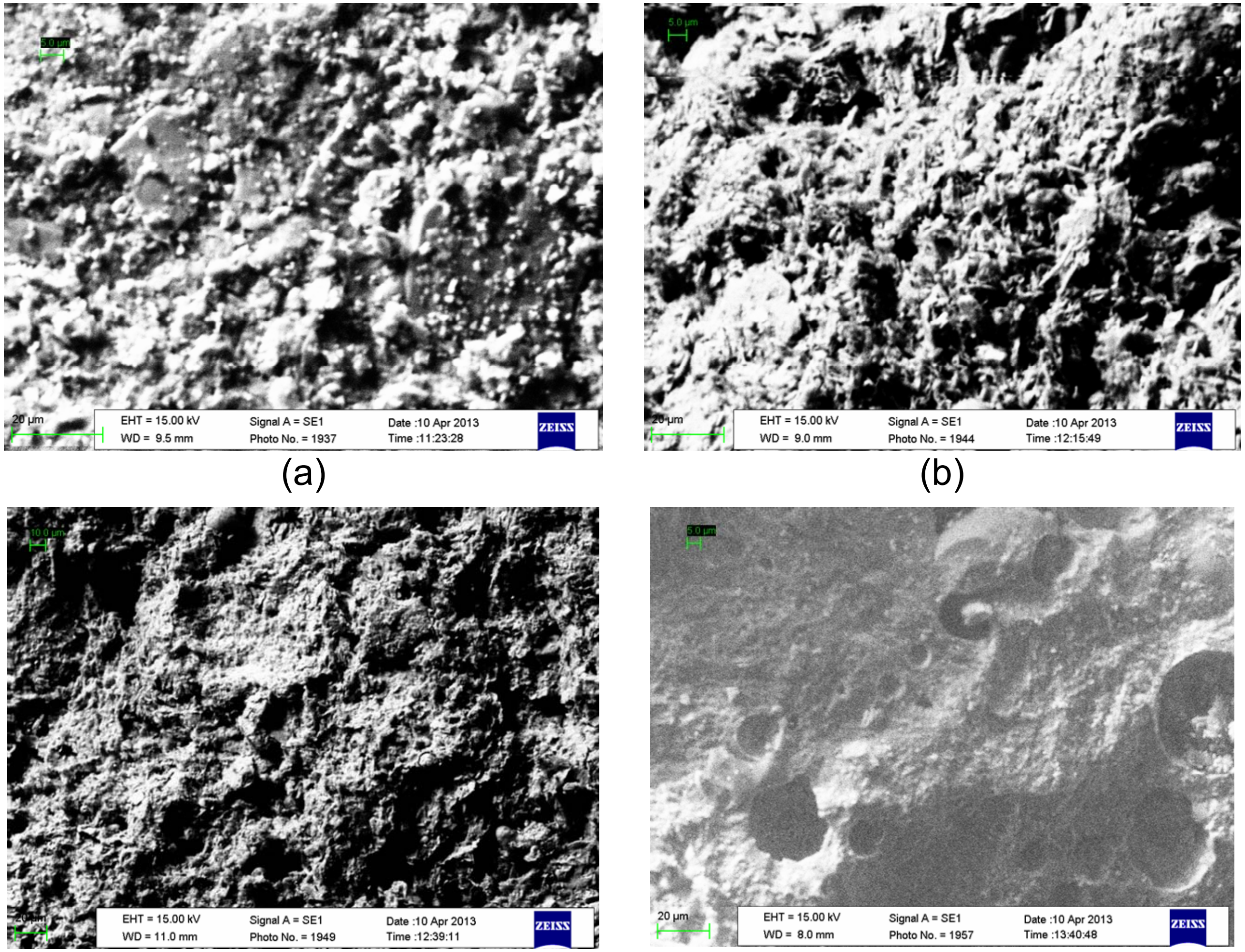
Effect of the addition of industrial powdery by-products

Effect of the %wt. addition of FA and/or EAFD in the clay mixture
on the thermal conductivity (k) & the bending strength (MOR) of the bricks (T_{sint}=1050°C)



- **EAFD**: MOR & k ≈ independent of %wt.
- **FA**: %wt. ↑ → MOR & k ↓
- **FA+EAFD**(5+5=10%wt.): Intermediate MOR & k values

Effect of firing temperature



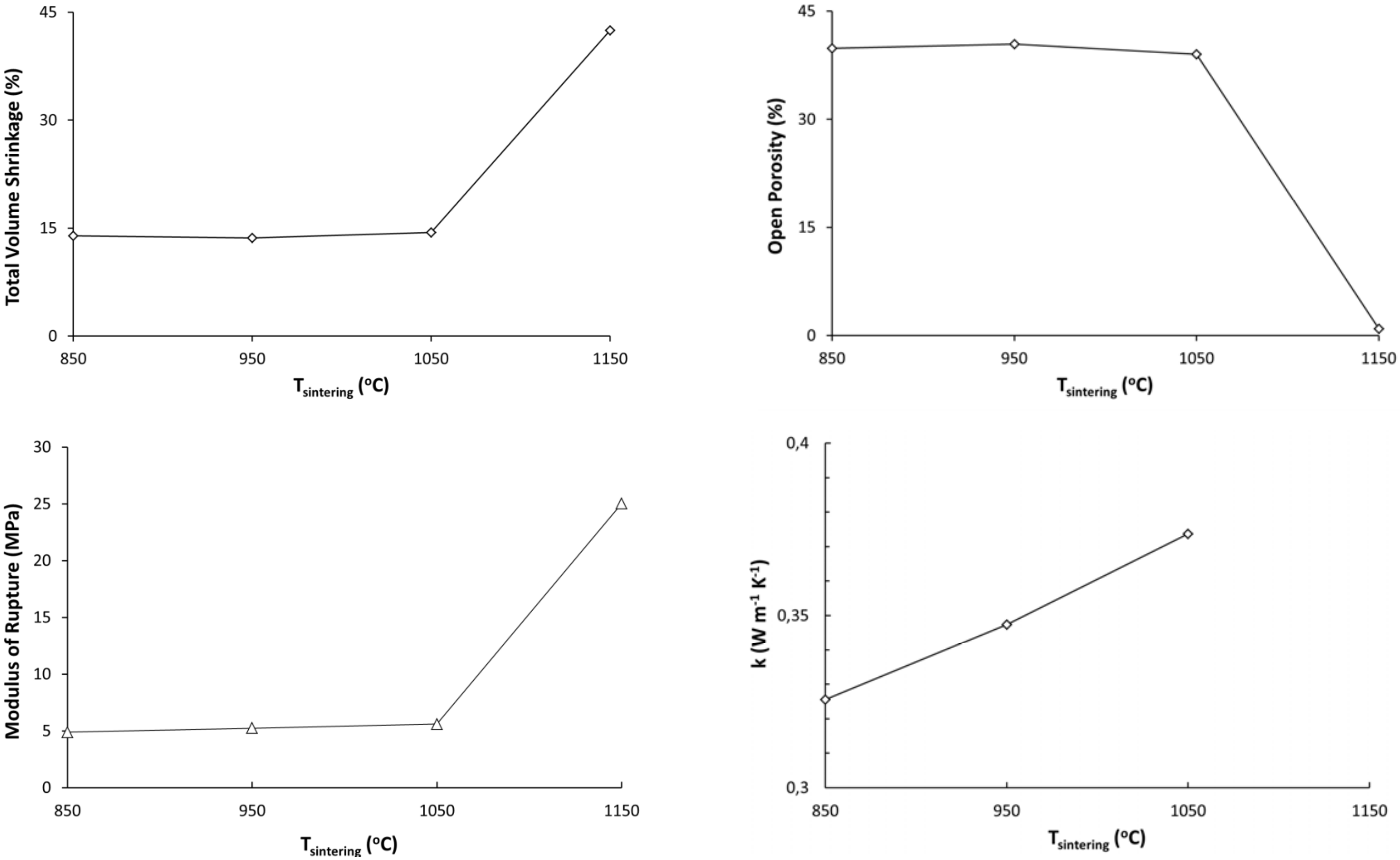
(a) (b)

(c) (d)

SEM micrographs of 5+5(FA+EAFD)%wt. content clay bricks fired at **850** (a), **950** (b), **1050** (c) & **1150** ^{o}C (d)

Effect of firing temperature

Volume shrinkage, open porosity, bending strength & thermal conductivity (k)
of 5+5(FA+EAFD)%wt. content clay bricks
fired at **850** (a), **950** (b), **1050** (c) & **1150** ^{o}C (d)



- T_{sint} = **850-1050ºC** → Slight variation in properties
- T_{sint} = **1150ºC** → TVS ↑↑, OP ↓↓, MOR ↑↑

CONCLUSIONS

- The **synergistic addition** of **power station fly ash** along with **steel-making dust** in a suitable combination (5+5 %wt.) **into clay minerals** for **bricks development** is **successfully** achieved towards **sustainable** use of **material** & **energy resources**.
- By appropriately **adjusting** the additive **mixture composition**, the **brick properties** can be **predicted** and **tailored** in order to meet the needs for specific ceramic applications.
- The **influence** of the **firing temperature**, especially at **1150ºC**, on the properties of the sintered ceramic bodies is emphasized.
- Carbon footprint evaluation of the firing process is currently underway, focusing on **possible CO_2 emission reductions**.

Acknowledgment

This research has been co-financed:

by the European Union (European Social Fund – ESF)

and Greek national funds

through the Operational Program "Education and Lifelong Learning" of the National Strategic Reference Framework (NSRF)

- Research Funding Program: **ARCHIMEDES III**. Investing in knowledge society through the European Social Fund.