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# Hydration characteristics of silica-alumina based cementitious materials composed of steel slag

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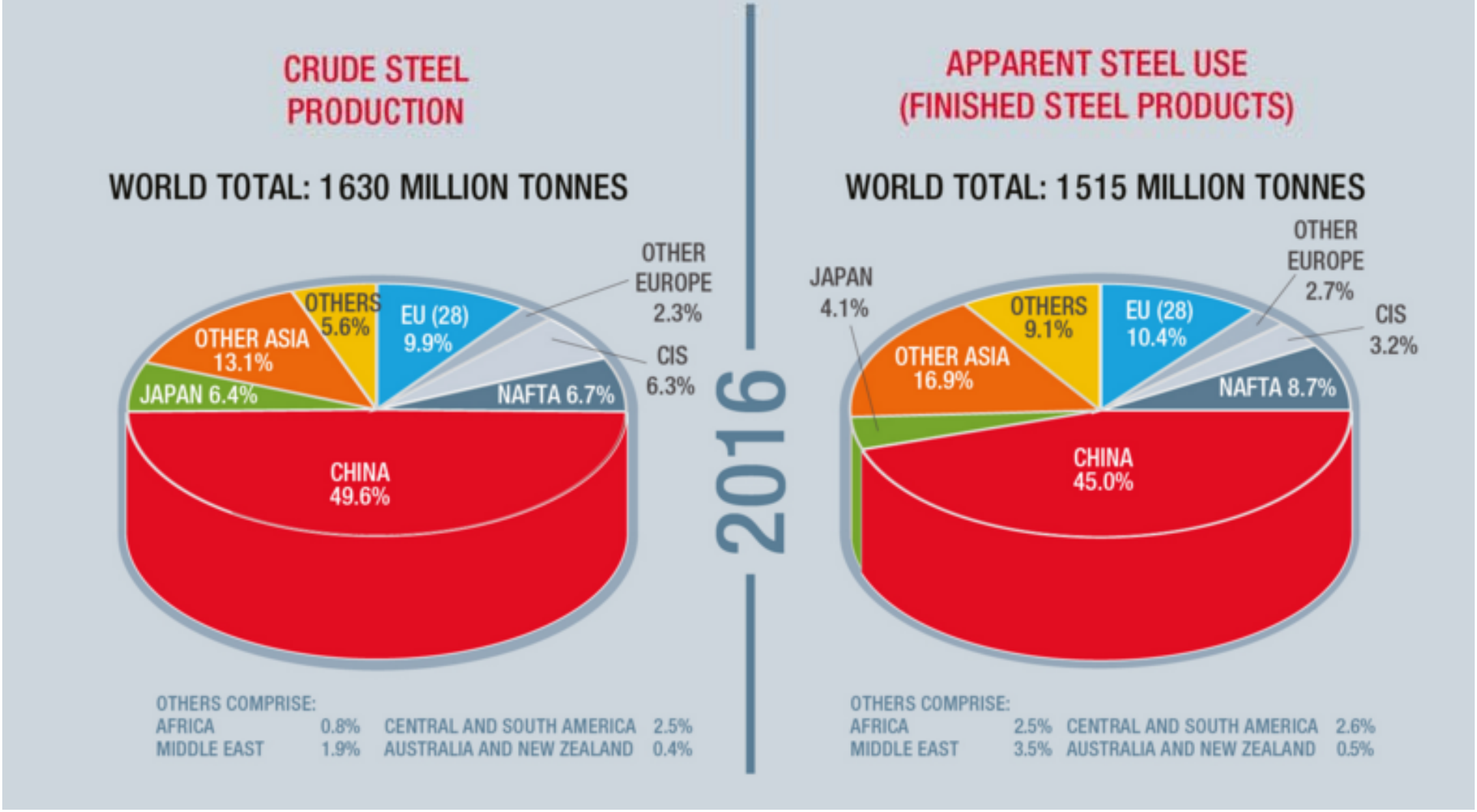
# Introduction

**Steel slag** is a solid waste generated during the steelmaking process.

Producing 1 ton of crude steel generates 0.1-0.15 ton of steel slag.

**How many quantities of steel slag produced every year in China?**

# Steel Production and Use: Geographical Distribution in 2016




《World Steel in Figures 2017》


《World Steel in Figures 2017》

**Using steel slag to produce construction materials is an effective way to largely consume this solid waste.**

**The high content of $P_2O_5$ in some steel slags leads to a serious retarding phenomenon in Portland cement, which limits the adding amount of steel slag in the traditional cement and concrete.**

**Table 1 Chemical composition of steel slag in China (wt%)**

| Steel Plants | CaO | $SiO_2$ | $Al_2O_3$ | $Fe_2O_3$ | MgO | FeO | $P_2O_5$ | MnO |
|---|---|---|---|---|---|---|---|---|
| A | 52.65 | 12.25 | 3.04 | 6.11 | 9.10 | 10.41 | 0.61 | 4.57 |
| B | 58.21 | 16.23 | 2.63 | 3.15 | 2.27 | 7.91 | 1.16 | 4.46 |
| C | 45.34 | 8.85 | 3.28 | 8.81 | 7.98 | 19.37 | 0.73 | 2.39 |
| D | 43.14 | 15.56 | 2.58 | 5.16 | 3.41 | 19.22 | 3.88 | 2.34 |
| E | 52.39 | 13.27 | 2.82 | 7.27 | 6.28 | 13.24 | 1.31 | 1.03 |

**Table 2 Phase composition of steel slag with different alkalinity (wt%)**

| Alkalinity | $C_3S$ | $C_2S$ | RO |
|---|---|---|---|
| 4.25 | 50-60 | 1-5 | 15-20 |
| 3.08 | 35-45 | 5-10 | 15-20 |
| 2.74 | 30-35 | 20-30 | 3-5 |
| 2.63 | 20-30 | 10-20 | 15-20 |
| 2.57 | 15-25 | 20-25 | 40-50 |
| 2.12 | -- | 20-30 | 15-20 |
| 1.25 | - | 5-10 | 7-15 |

# Occurrence state of phosphorus in steel slag

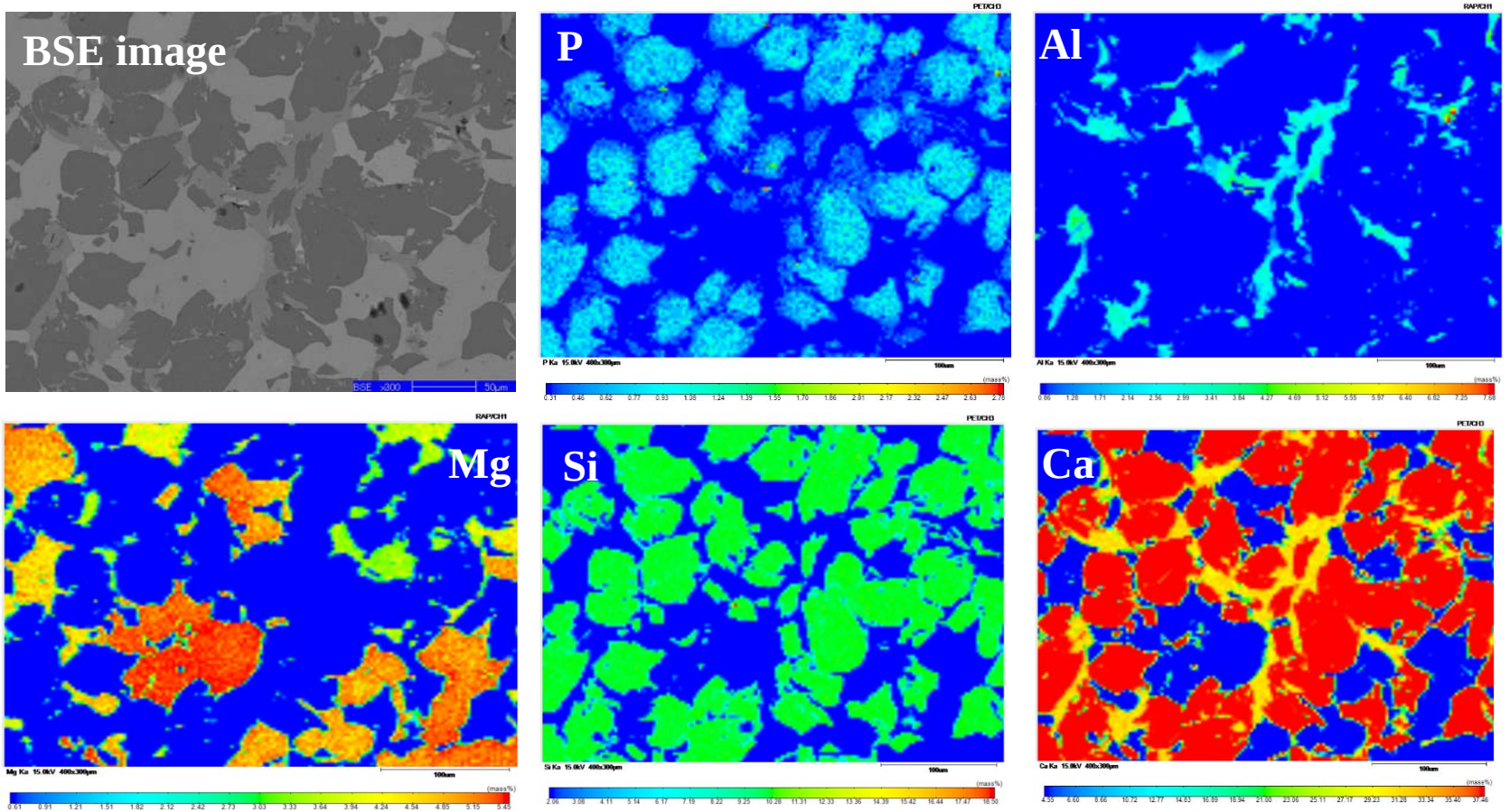
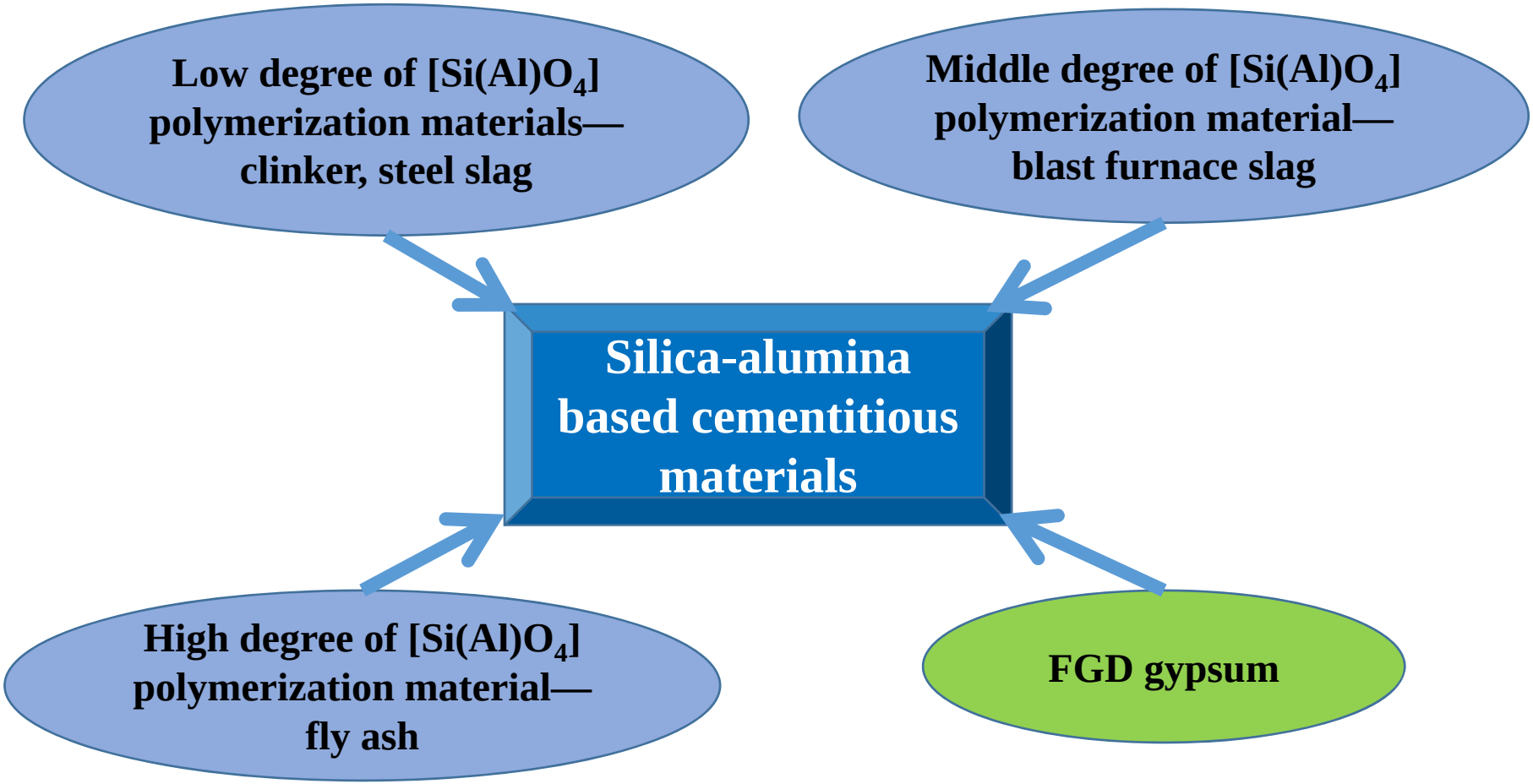



**Fig. 1 Electron probe microanalysis (EPMA) elemental mappings of steel slag**

**Phosphorus is enriched apparently in steel slag, and it is mainly occurring in $Ca_2SiO_4$ ($C_2S$) and $Ca_3SiO_5$ ($C_3S$) with $P_2O_5$ content of 3.2-7.5 wt.%.**

# Compound synergistic effect of industrial solid wastes



# Mechanical properties

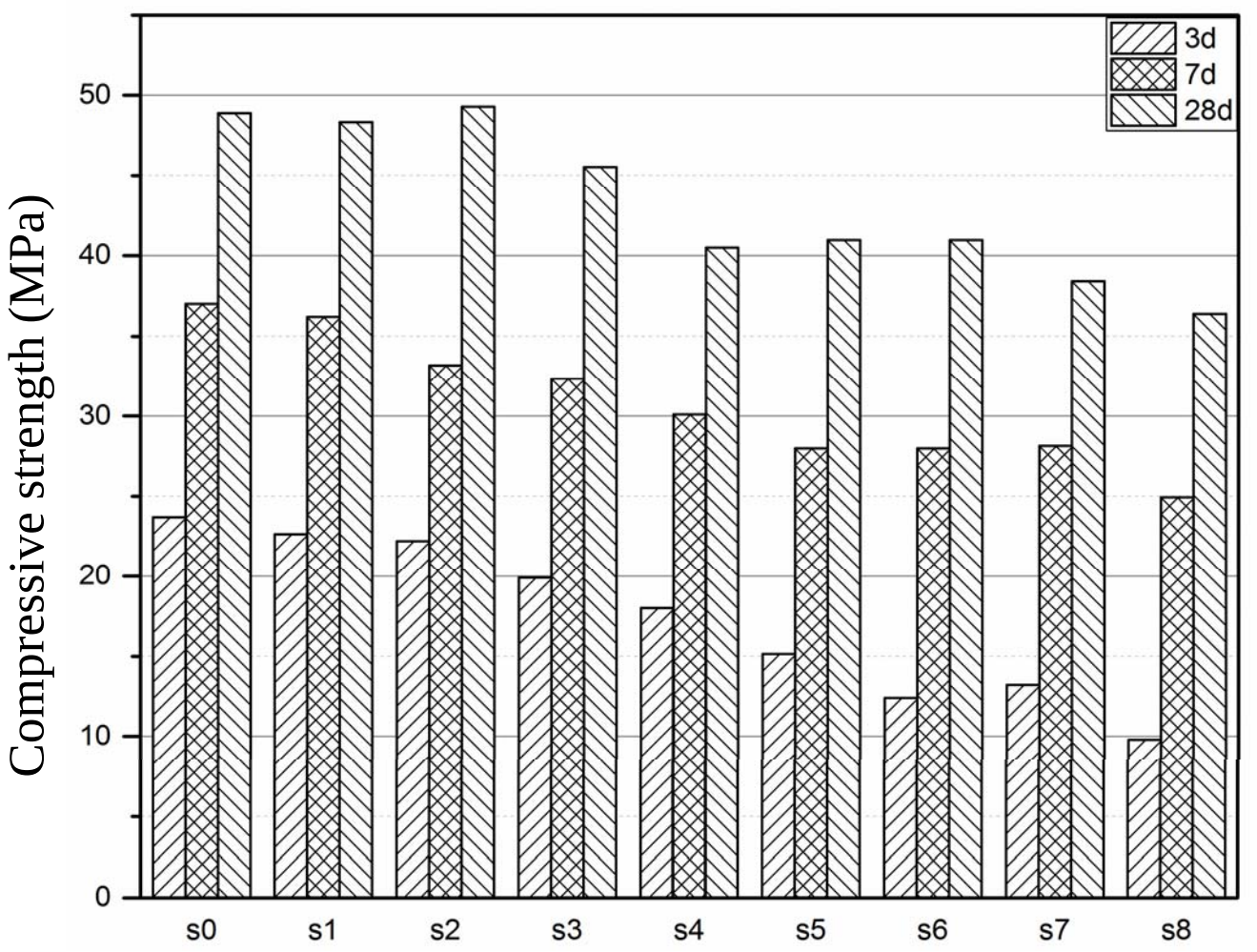



**Fig. 2 Compressive strength of silica-alumina based cementitious materials composed of steel slag**

# Final setting time

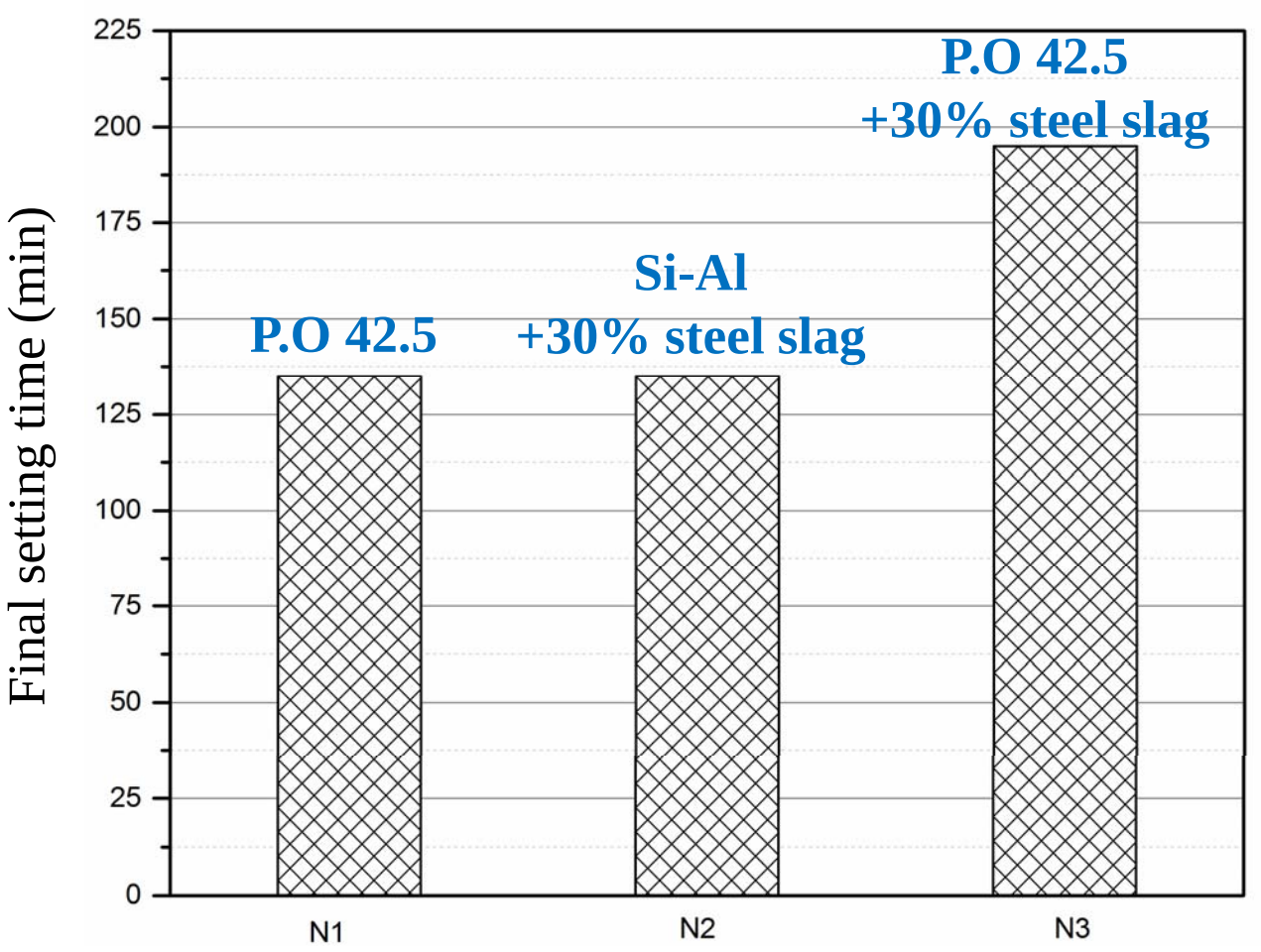



**Fig. 3 Final setting time of mortars**

# Hydration products

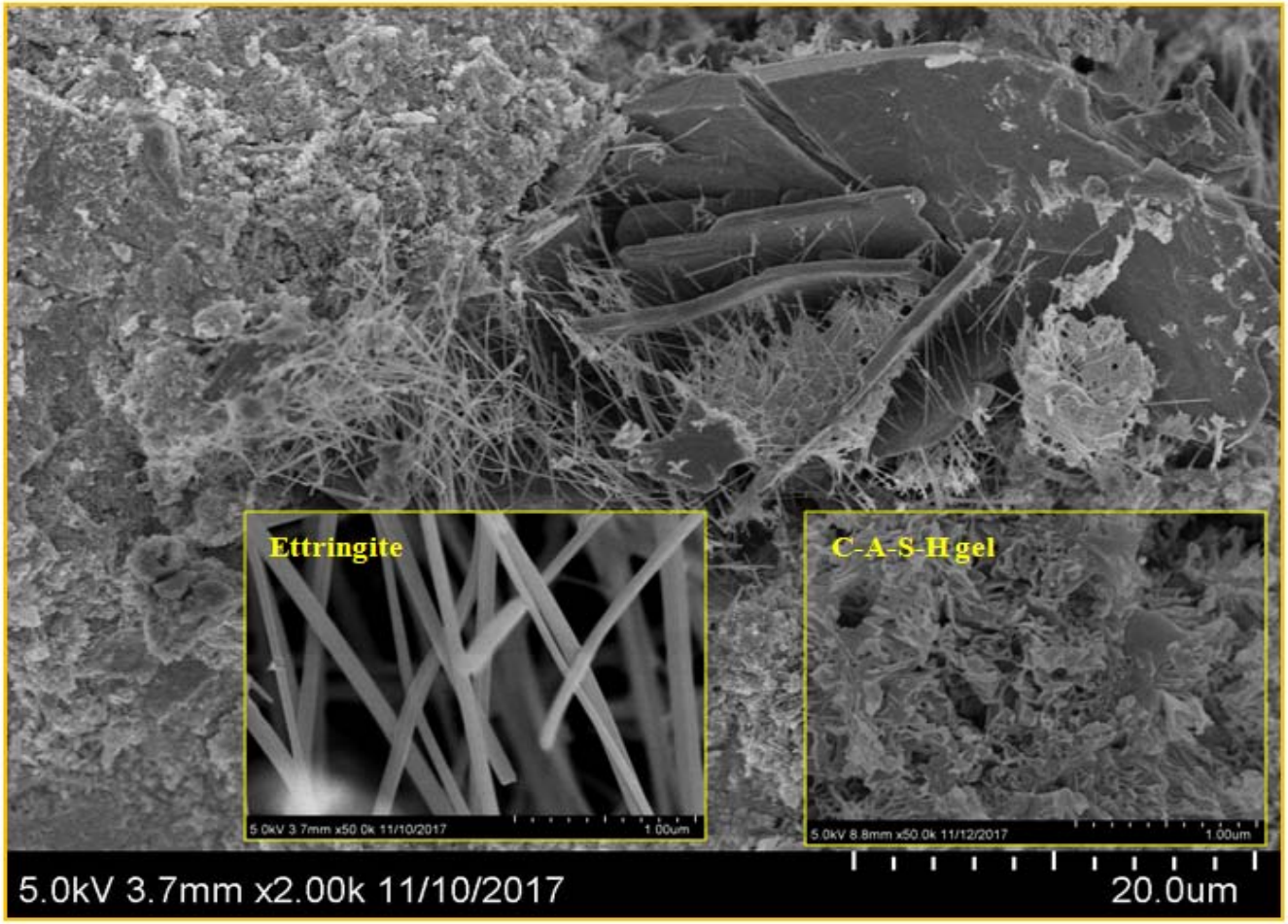



**Fig. 4 SEM image of hydration products of silica-alumina based cementitious materials composed of steel slag**

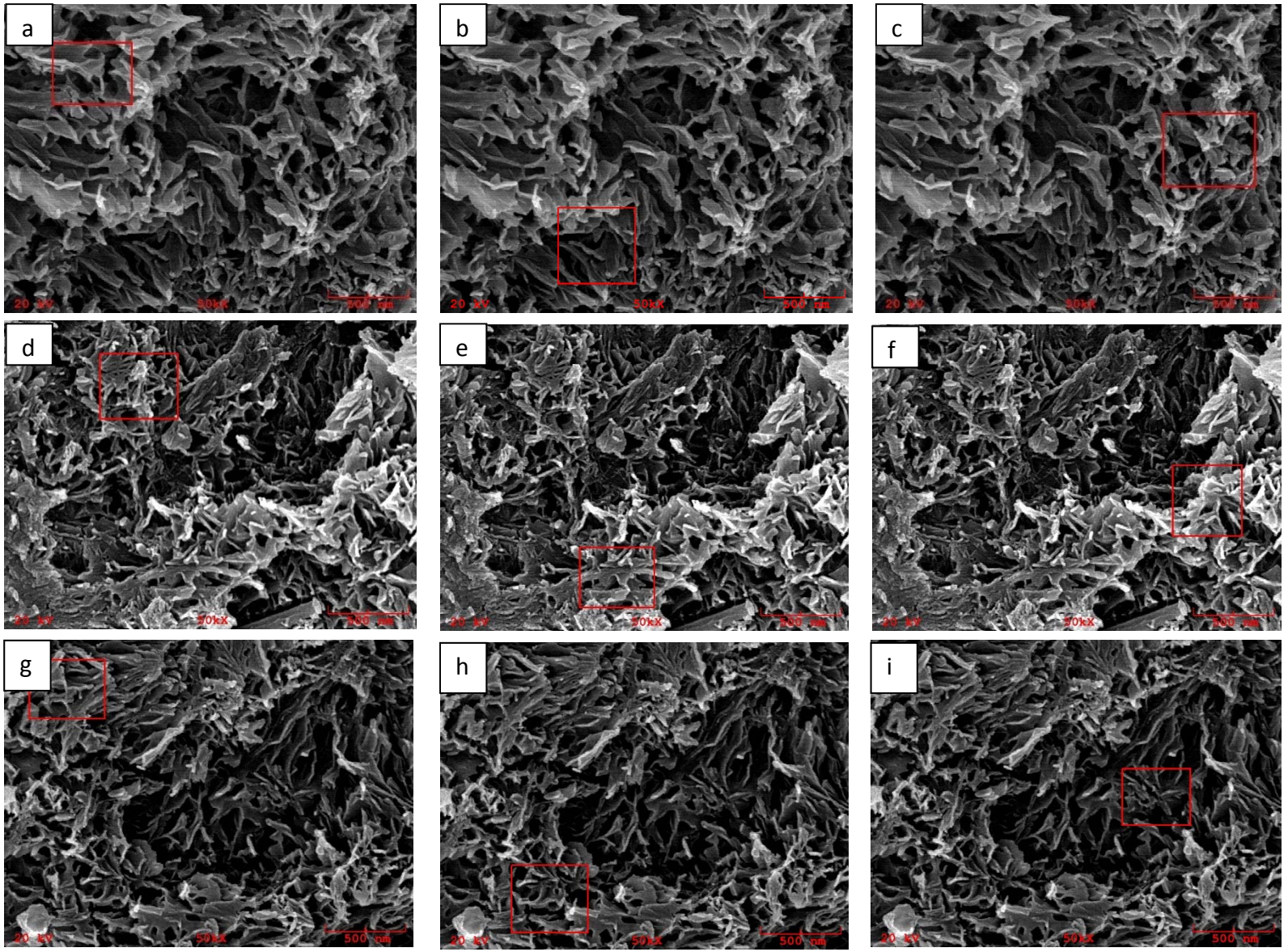
**The needle-like ettringite and amorphous C-A-S-H gel play a positive role in promoting densification of the paste structure.**

# SEM-EDS analysis of C-A-S-H gels

**G0**

**G2-5% $P_2O_5$**

**G2-10% $P_2O_5$**



# Phosphorus content in the C-A-S-H gels

**Table 3 SEM-EDS results (Atomic%)**

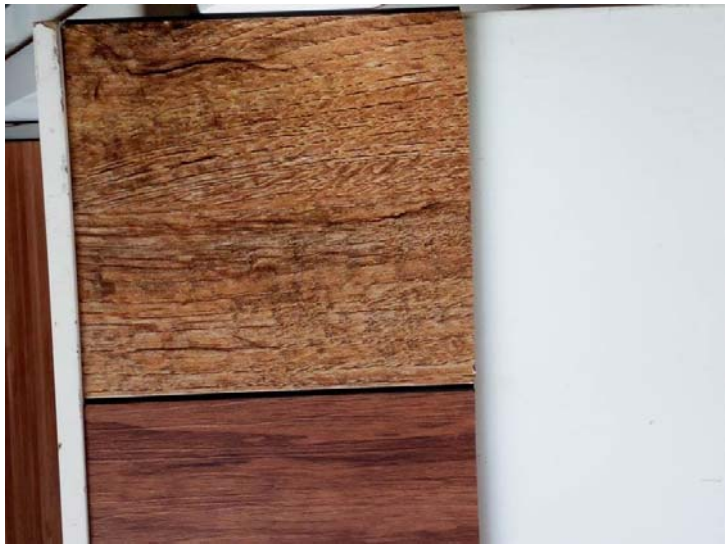
| Spots | O | Mg | Al | Si | S | P | Ca |
|---|---|---|---|---|---|---|---|
| a | 42.17 | 1.82 | 5.78 | 15.77 | 1.07 | - | 32.65 |
| b | 36.13 | 3.49 | 6.68 | 16.28 | 1.18 | - | 35.03 |
| c | 39.20 | 1.77 | 5.24 | 14.05 | 0.91 | - | 30.70 |
| d | 53.63 | 1.83 | 6.02 | 11.15 | 1.42 | 2.53 | 15.37 |
| e | 55.96 | 1.58 | 5.22 | 9.36 | 1.54 | 2.59 | 15.57 |
| f | 56.79 | 2.03 | 5.03 | 9.56 | 1.05 | 2.11 | 14.48 |
| g | 60.91 | 2.65 | 5.10 | 12.32 | 1.18 | 2.54 | 15.03 |
| h | 53.66 | 2.51 | 5.19 | 12.81 | 1.18 | 2.65 | 17.13 |
| i | 48.12 | 2.95 | 5.70 | 14.17 | 1.40 | 1.71 | 20.94 |

**The phosphorus in steel slag was involved into the hydration reaction to form C-A-S-H gel. (Hydroxyapatite was not found in the hydration products.)**

# Utilization of red mud in materials research

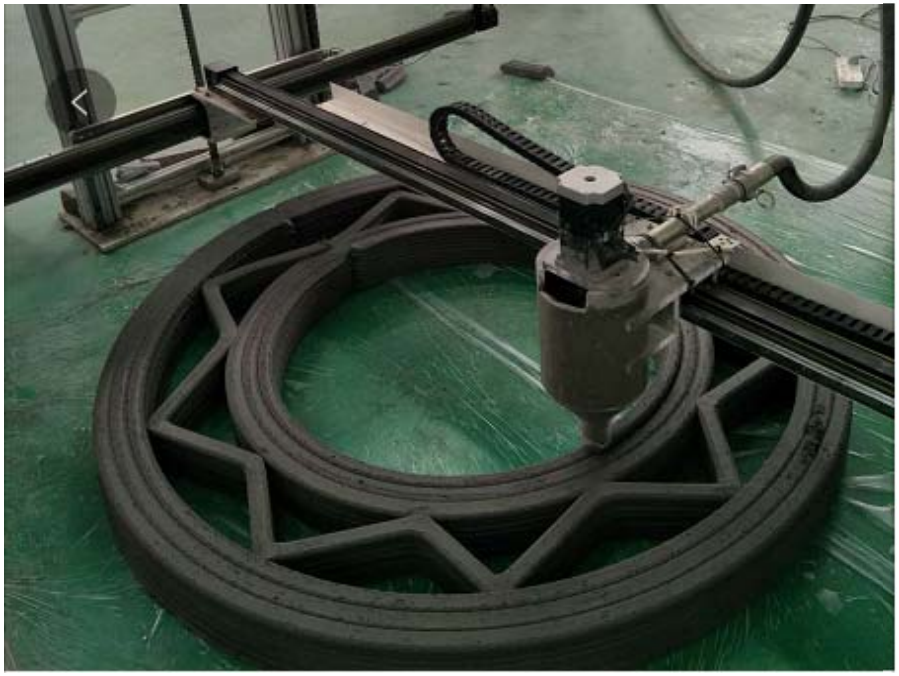
**Red mud road base material**

# Utilization of red mud in materials research



**Red mud composite plate**

# Iron tailings 3D materials research



# Related Publications

**[1] N. Zhang**, H. Sun, X. Liu, J. Zhang. Early-age characteristics of red mud-coal gangue cementitious material. *Journal of Hazardous Materials*, 2009, 167(1-3): 927-932. (SCI, IF: 6.065)

**[2] N. Zhang**, X. Liu, H. Sun, L. Li. Pozzolanic behaviour of compound-activated red mud-coal gangue mixture. *Cement and Concrete Research*, 2011, 41(3): 270-278. (SCI, IF: 4.762)

**[3] N. Zhang**, X. Liu, H. Sun, L. Li. Evaluation of blends bauxite-calcination-method red mud with other industrial wastes as a cementitious material: properties and hydration characteristics. *Journal of Hazardous Materials*, 2011, 185(1): 329-335. (SCI, IF: 6.065)

**[4] N. Zhang**, H. Li, X. Liu. Hydration mechanism and leaching behavior of bauxite-calcination-method red mud-coal gangue based cementitious materials. *Journal of Hazardous Materials*, 2016, 314: 172-180. (SCI, IF: 6.065)

**[5] N. Zhang**, H. Li, Y. Zhao, X. Liu. Hydration characteristics and environmental friendly performance of a cementitious material composed of calcium silicate slag. *Journal of Hazardous Materials*, 2016, 306: 67-76. (SCI, IF: 6.065)

**[6]** Xiaoming Liu, **Na Zhang**, Yuan Yao, Henghu Sun, Huan Feng. Micro-structural characterization of the hydration products of bauxite-calcination-method red mud-coal gangue based cementitious materials. *Journal of Hazardous Materials*, 2013, 262: 428-438. **(**SCI, IF: 6.065)

# Related Publications

**[7]** Xiaoming Liu, **Na Zhang**, Henghu Sun, Jixiu Zhang, Longtu Li. Structural investigation relating to the cementitious activity of bauxite residue – Red mud. *Cement and Concrete Research*, 2011, 41(8): 847-853. (SCI, IF: 4.762)

**[8]** Xiaoming Liu, **Na Zhang**. Utilization of red mud in cement production: a review. *Waste Management and Research*, 2011, 29(10): 1053-1063. **(**SCI, IF: 1.803**)**

**[9]** Xiaoming Liu*, Xibin Zhao, Haifeng Yin, Jiaolong Chen, **Na Zhang***. Intermediate-calcium based cementitious materials prepared by MSWI fly ash and other solid wastes: hydration characteristics and heavy metals solidification behavior. *Journal of Hazardous Materials, 2018,* 349: 262-271. **(**SCI, IF: 6.065)

# THANKS FOR YOUR ATTENTION

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