

# ALKALI ACTIVATED FOAMS FROM SLAG

**Mark ČEŠNOVAR<sup>1,2</sup>, Katja TRAVEN<sup>1</sup>, Vilma DUCMAN<sup>1</sup>**

<sup>1</sup> Slovenian National Building and Civil Engineering Institute (ZAG), Dimičeva 12, 1000 Ljubljana, SLOVENIA

<sup>2</sup> International Postgraduate School Jozef Stefan, Jamova 39, 1000 Ljubljana, SLOVENIA

*mark.cesnovar@zag.si*

## Introduction

Alkali activated materials (AAM) are inorganic aluminosilicate based materials, mainly produced from fly ashes and metallurgical slags or clays containing high percentage of  $\text{Al}_2\text{O}_3$  and  $\text{SiO}_2$  with high solubility in basic media. As a general rule, materials with high reactive silica content are more plentiful than materials containing reactive alumina.<sup>1,2</sup> The alkali activation technology offers possibility for utilisation of secondary materials from metallurgical processes into a new group of useful building products. Steel slag based alkali activated materials have high mechanical strength, good fire and high thermal resistance at elevated temperatures and in case of low density (lightweight foams) also low thermal conductivity.<sup>3</sup> The alkali-activated (AA) slag-based lightweight foams are a promising alternative for insulation materials products for the civil engineering sector and industrial use. The slags are by-products of high temperature metallurgical processes that are primarily used to separate the metal and non-metal. Various types of aluminosilicate rich slag can be used in the alkali activation process.

In the present study, the electric arc furnace steel slag (Slag A) and the ladle furnace basic slag (Slag R) from different metallurgical industries in Slovenia were selected for alkali activation, and foaming process.

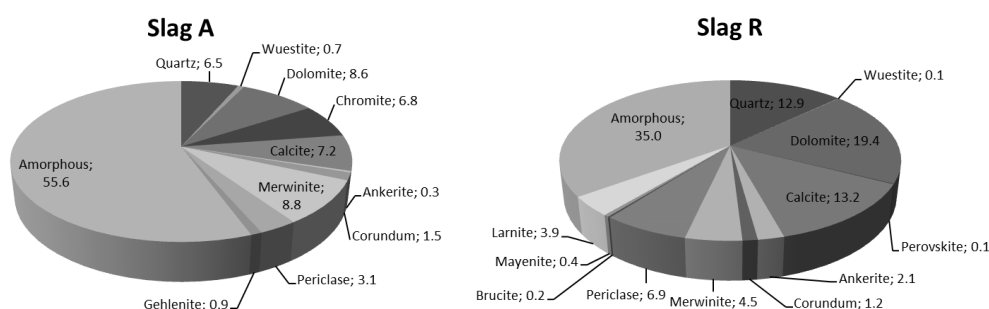
## Experimental

Chemical analysis (XRF) of both slags is presented in Table 1. Electric arc furnace slag is produced during the manufacture of crude steel by the electric arc furnace (EAF) process.<sup>4</sup> The ladle furnace basic slag is produced in the secondary refining stage, when the steel is desulphurised in the transport ladle.<sup>5</sup>

**Table 1:** Chemical composition of Slag A and Slag R used in this study

Elements (wt%)	SiO <sub>2</sub>	Al <sub>2</sub> O <sub>3</sub>	Fe <sub>2</sub> O <sub>3</sub>	CaO	MgO	Na <sub>2</sub> O	K <sub>2</sub> O	Cr <sub>2</sub> O <sub>3</sub>	MnO	LOI	OTH
Slag A	21.05	8.54	11.37	20.87	14.87	0.13	0.17	3.76	2.24	14.15	2.80
Slag R	13.69	5.20	4.64	27.85	23.25	0.28	0.14	0.18	0.62	20.47	4.43

The quantitative determination of mineral phases (XRD-Rietveld) is shown in Figure 1. X-ray diffraction analysis has confirmed the presence of an amorphous phase in both slags. The particle size distributions and specific surface area of slag A and slag R is presented in Table 2.

**Figure 1:** Mineral composition and the quantitative determination of phases in Slag A and Slag R**Table 2:** The particle size distribution of used precursors

Precursor	C (10%) / (μm)	C (50%) / (μm)	C (90%) / (μm)	Surface area – BET (m <sup>2</sup> /g)
Slag A	0.80	5.94	28.71	7.61
Slag R	0.83	5.45	24.75	3.52

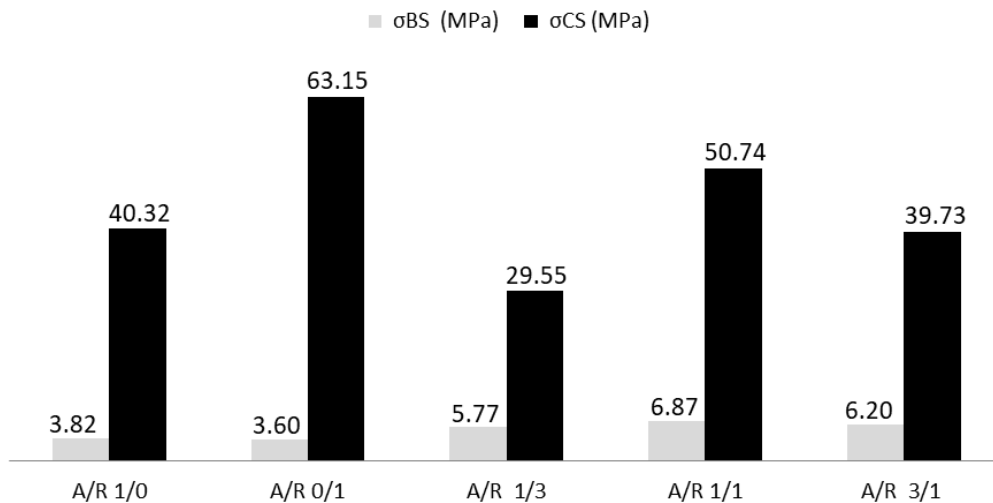
The A and R slags with various mixture ratios (A/R: 1/0, 0/1, 1/3, 1/1 and 3/1) were activated with sodium silicate with the activator/slag ratio 0.5 and the amount of sodium silicate was 33.3 wt% for all prepared mixtures (Table 3). Sodium silicate Crystal 0112 with 2:1 of SiO<sub>2</sub>/Na<sub>2</sub>O was used (Tennanants Distribution Limited, UK). All mixtures were cured in a heat-chamber for 3 days at 70°C to develop suitable mechanical strength.

**Table 3:** Composition of the investigated AA mixtures (all in wt%)

Sample designation	Slag A	Slag R
A/R 1/0	66.7	/
A/R 0/1	/	66.7
A/R 1/3	16.7	50.0
A/R 1/1	33.3	33.3
A/R 3/1	50.0	16.7

## Results

To obtain optimal strength (bending and compressive strengths) the study in first stage has focused on the influence of the precursor to activator solution mix ratio. Based on the results of the mechanical properties as presented in Figure 2 the maximum bending and suitable compressive strength was in the case of mixture A/R 1/1 which was thus selected as optimal mixture.



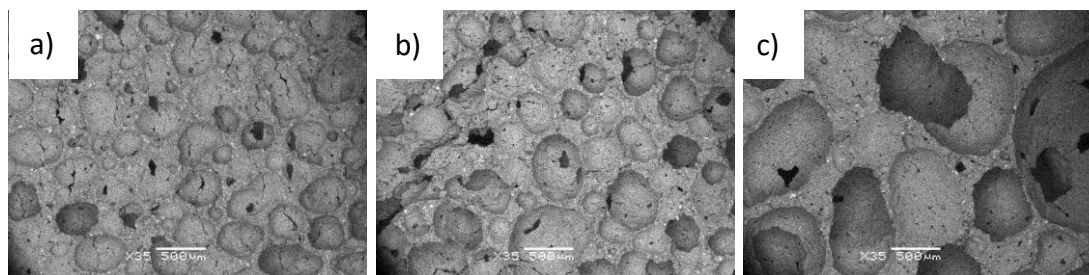
**Figure 2:** Bending ( $\sigma_{BS}$ ) and compressive ( $\sigma_{CS}$ ) strength of slag mixtures

The AA mixture A/R 1/1 was further used for the development of AA lightweight foams. Thermal and mechanical properties of slag-based lightweight foams, beside precursor source are strongly dependent on the type and amount of alkali activator, the foaming agent and the curing regime.<sup>6</sup> In the present study different proportions ranging from 1 to 2% of the selected chemical foaming agent ( $H_2O_2$ ) were added to the optimal mixture A/R 1/1 activated with sodium silicate. Densities and mechanical properties of foams are shown in Table 4.

**Table 4:** Foam content effect on density and mechanical properties

Foam agent content (%)	Density ( $gcm^{-3}$ )	Bending strength (MPa)	Compressive strength (MPa)
1.0	0.85	3.47	5.00
1.5	0.73	1.86	3.67
2.0	0.59	0.95	1.36

The SEM images in Figure 3 show the morphology of AA lightweight foam with different proportions of foaming agent ( $H_2O_2$ ). Diameter of the pores is in the range from app. 400  $\mu m$  to over 1 mm for 1% of  $H_2O_2$  or 2%  $H_2O_2$ , respectively.



**Figure 3:** SEM images of AA foam with a) 1% H<sub>2</sub>O<sub>2</sub>, b) 1.5% H<sub>2</sub>O<sub>2</sub> and c) 2% H<sub>2</sub>O<sub>2</sub>

## Conclusions

Two types, EAF (A) and LS (R) metallurgical slags from Slovenia were characterised prior to alkali activation with sodium silicate. Both slags were mixed in ratios as follows A/R 1:0, 0:1, 1:3, 1:1 and 3:1, all activated with the activator to slag ratio 0.5 and cured under 70°C for 3 days. The values of bending strength were in the range from 3 to 6 MPa, and the compressive strength varied from 29 to 63 MPa.

To the optimal mixture (A/R 1/1), a foaming agent in amounts from 1 to 2% of H<sub>2</sub>O<sub>2</sub> was further added what resulted in densities from 0.85 to 0.59 g/cm<sup>3</sup>. Bending and compressive strength are being decreased from 3.47 to 0.95 MPa, and from 5.0 to 1.36 MPa, respectively what is slightly lower than for aerated concrete<sup>7</sup> but still acceptable for non-load bearing application.

## Acknowledgement

Work has been financed under project FLOW: Lightweight alkali activated composite foams based on secondary raw materials, Project ID-94, 2017 ERA-MIN 2 Joint Call.

## References

1. C. Shi, A. Fernández Jiménez, A. Palomo, "New cements for the 21st century: The pursuit of an alternative to Portland cement", *Cement Concrete Res*, **41** 750-763 (2011).
2. J. C. Petermann, A. Saeed, M. I. Hammons, "Alkali-Activated geopolymers: A literature review", AFRL-RX-TY-TR-2010-0097, approved for public release, 88ABW-2012-2030, (2012).
3. S. A. Bernal, J. L. Provis, "Durability of Alkali-Activated Materials: Progress and Perspectives", *J Am Ceram Soc*, **97** (4) 997-1008 (2014).
4. <http://www.euroslag.com/products/eaf/> (Accessed on 09/01/19)
5. J. Setién, D. Hernández,, J. J. González, "Characterization of ladle furnace basic slag for use as a construction material", *Constr Build Mater*, **23** (5) 1788-1794, (2009).
6. L. Korat, V. Ducman, "The influence of stabilizing agent SDS on porosity development in alkali-activated fly ash based foams", *Cement Concrete Comp*, **80** 168-174 (2017).
7. L. Miccoli, P. Fontana, N. Silva, A. Klinge, C. Cederqvist, O. Kreft, D. Qvaeschning, C. Sjöström, "Composite UHPC-AAC/CLC facade elements with modified interior plaster for new buildings and refurbishment. Materials and production technology.", *J. Facade Des Eng*, **3** 91-102 (2015).