

## UPCYCLING OF BIO-WASTE ASHES INTO ADDITIVE FOR CONCRETE

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### ABSTRACT

Ashes from different industrial processes are a significant burden to the environment. One promising alternative to landfilling is upcycling the ashes into a valuable resource for concrete. This paper focuses on the use of waste ashes as fine fraction of lightweight aggregates. Thanks to their open porosity and high water absorption, the ashes can retain water during mixing and release it to concrete in the process referred to as "internal curing". We tested two types of ashes: bottom ashes and rice husk ashes. The performance of concretes with the preselected ashes was assessed, focusing on the mechanical properties, creep, autogenous and drying shrinkage. The ashes can replace part of the mineral aggregates (fine fractions of sand) in concrete, which saves resources and enhances the properties of the concrete, primarily thanks to internal curing. This can be of special benefit for concretes hardening in harsh climates in lack of appropriate curing. The study shows that the porous ashes can significantly reduce the autogenous shrinkage and improve the strength of concrete.

**KEYWORDS:** *Internal curing, Ashes, Lightweight aggregates, Concrete, Upcycling*

### 1. Introduction

Proper management of ashes poses a significant strain on the incineration industry. Incorporation of ashes in concrete could provide a high-capacity sink. Ashes that improve certain properties of concrete, rather than acting just as a filler, are most relevant. A prominent example are siliceous ashes with pozzolanic activity, most often fly ashes from coal combustion, but also e.g. rice husk ashes (Agarwal 2006). In this work, we focus on other functionalities, stemming from the high water absorption potential of certain types of ashes. Thanks to the latter property, porous ashes can deliver water to the hardening concrete in a process referred to as "internal curing" (Bentur et al. 2001). Our previous studies have shown that this is a feasible strategy towards upcycling of waste and improving concrete performance at the same time (Wyrzykowski et al. 2016). The action of porous ashes relies on the same principle as that of the lightweight aggregates, LWA (synthetic or natural porous aggregates). Namely, the ashes are expected to absorb water (either in a presaturation step or during concrete mixing) and release it to concrete to compensate for the water lost due to evaporation from fresh concrete or due to consumption by cement. Internal curing can be especially beneficial for concretes hardening in harsh drying conditions, i.e. at elevated temperature and in dry climate and where traditional, external water curing cannot be applied.

We studied two different types of ashes: bottom ash (BTA) and rice husk ash (RHA). They were selected based on their high open porosity (see Fig. 1) and high water absorption and desorption potential. The ashes were employed as partial sand replacement in concrete. We tested the influence of ashes on mechanical properties (compressive strength), creep and shrinkage.

## 2. Materials and methods

We tested three different concrete mixes: a reference mix (REF), and mixes with BTA and RHA. BTA originated from coal boilers of paper industry. BTA was sieved from an original stock and the fraction 300-600  $\mu\text{m}$  was used. RHA was used directly as obtained from the burning process. The grains had sizes up to about 300  $\mu\text{m}$  (see Fig. 1).

The amount of the ashes in concrete mix was calculated following their internal curing potential according to the approach proposed in (Bentz et al. 2005). The water absorption potential of the ashes was estimated as 10% and 20% for the BTA and the RHA, respectively. The w/b was increased from 0.51 to 0.56 for the concretes with ashes. The ashes replaced aggregates in an amount corresponding to 12% or 7% of volume for BTA or RHA, respectively. The mix compositions are presented in Table 1.

Table 1. Mix composition of concretes (in  $\text{kg}/\text{m}^3$  of concrete)

Material/Concrete mix	REF	BTA	RHA
Sand 0-4 mm	909	691	787
Gravel 4-16 mm	910	908	908
Porous ash (BTA or RHA)	0	174	87
Cement CEM I 42.5N	235	235	235
Fly Ash (pozzolanic)	113	113	113
Superplasticizer (mass-% cement)	0.12%	0.52%	1.57%
Water	177	177	177
Add. water	0	18	18
w/b	0.51	0.56	0.56

### 2.1 Shrinkage and creep

Shrinkage and creep were measured on prismatic samples  $120 \times 120 \times 360 \text{ mm}^3$ . The prisms were demolded at 1 d and the steel markers were glued on two faces of each specimen (gauge length 250 mm). The length change measurements were carried out between the steel markers using manual dilatometer. The strains were referenced to the length at 1 d. After the first length measurement, the specimens were placed in climate room at  $70 \pm 3 \text{ \%RH}$  and  $20 \pm 0.3 \text{ }^\circ\text{C}$ . Two groups of specimens were used: sealed with aluminum foil (used for autogenous shrinkage and basic creep) and with open surfaces (used for total shrinkage and drying creep). In creep measurements, specimens were loaded at 2 d in hydraulic loading cells to a stress corresponding to 33% of the compressive strength at 2 d (see Section 2.2) and the load was updated at 28 d to 33% of the compressive strength at that age.

### 2.2 Strength

Compressive strength was measured on 150-mm cubes according to EN 12390-3:2009 at different ages (2-91 d). The cubes were demolded at the age of 1 d and kept underwater at  $20 \pm 2 \text{ }^\circ\text{C}$  or exposed to drying at  $57 \pm 3 \text{ \%RH}$  and  $20 \pm 0.3 \text{ }^\circ\text{C}$ . Duplicate specimens were measured per mix and age. Standard deviation was 0.5 MPa on average and 2 MPa at most.

### 2.3. SEM-BSE

The porous ashes were dried in an oven at  $50 \text{ }^\circ\text{C}$ , impregnated under vacuum with modified bisphenol-A epoxy resin and polished with polycrystalline diamond suspensions. After carbon coating, the samples

were imaged with an environmental scanning electron microscope (ESEM-FEG XL30) in the backscattered electron mode (SEM-BSE).

### 3. Results

The Mercury Intrusion Porosimetry (MIP) measurements (not presented here in detail, carried out according to the same procedure as in (Wyrzykowski et al. 2016)) revealed relatively large dominant pore sizes,  $0.4\ \mu\text{m}$  for the BTA and  $0.8\ \mu\text{m}$  for the RHA. According to the criteria established in our previous works (Ghourchian et al. 2013, Wyrzykowski et al. 2016), these results allow to identify the porous ashes as promising internal curing agents in concrete.

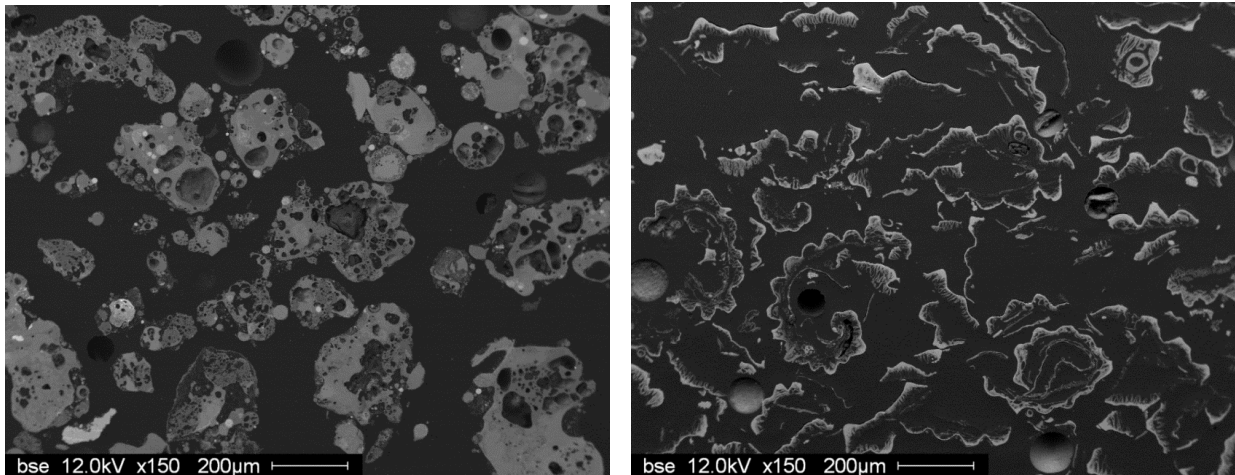


Figure 1. SEM-BSE images of the polished particles of BTA (left) and RHA (right). Large pores (from micrometres to several tenths of micrometres) that are opened to the surface can serve as water reservoirs for internal curing.

In Fig. 2 the results of the compressive strength tests are presented. The first feature visible on the graphs is that the curing under drying conditions leads to a significant reduction of strength. On the other hand, the addition of porous ashes led to improvement of strength. In fact, the presence of both types of ashes allowed a partial compensation of the effect of poor curing – the concretes with ashes exposed to drying from early age could reach similar strength at 28 d (BTA) and at 91 d (RHA) as the reference concrete cured underwater. The particularly positive effect of the RHA on strength in both curing regimes was likely due to the reactivity of the RHA. According to EDX analysis (not presented here), the RHA are composed in major part of Si. Thus, high pozzolanic activity can be expected, especially considering the high fineness of the RHA (see Fig. 1, right) (Agarwal 2006).

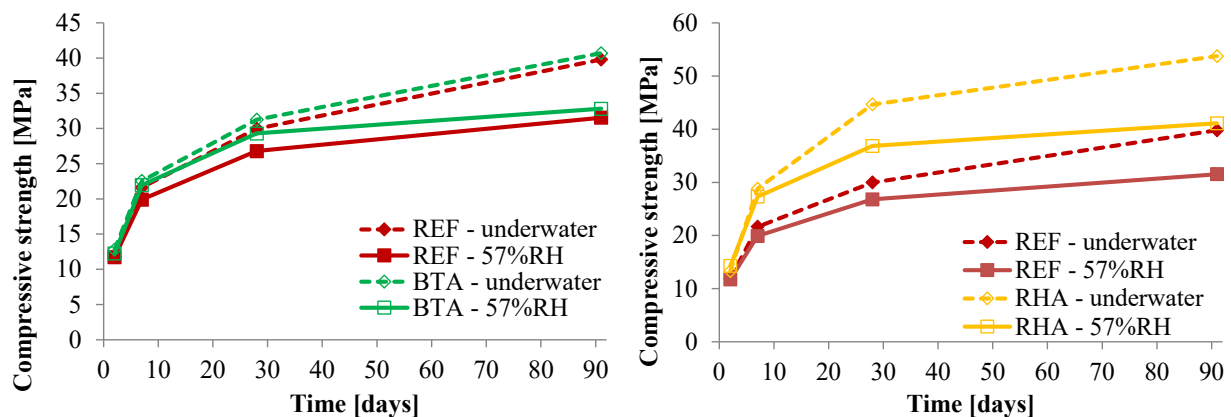


Figure 2. Compressive strength results of the reference concrete and concrete with BTA (left) and concrete with RHA (right). Two curing regimes were applied: underwater curing and drying at 57%RH.

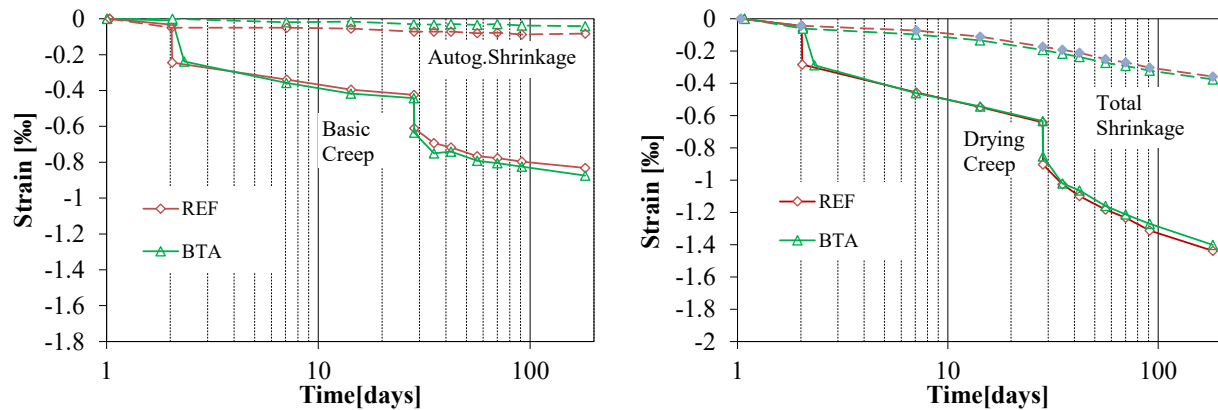


Figure 3. Shrinkage and creep measurements of REF concrete and concrete with BTA: sealed samples (autogenous shrinkage and basic creep, left) and drying at 70%RH (total shrinkage and drying creep, right).

The results of creep measurements in Fig. 3 show that BTA has no negative effect on creep deformations or total shrinkage during drying. A clear positive effect was observed regarding autogenous shrinkage (Fig. 3 left) – autogenous shrinkage at 180 d was reduced from 83  $\mu\text{m}/\text{m}$  for the REF concrete down to 41  $\mu\text{m}/\text{m}$  for the BTA concrete. This reduction can be attributed to the internal curing.

#### 4. Conclusions

The porous ashes: bottom ash and rice husk ash (BTA and RHA) tested here can act as efficient internal curing agents and hence compensate for poor curing of concretes exposed to drying from early age. In addition to the benefit of better curing, it is most likely that the porous additives have themselves a positive effect on strength. In fact, the compressive strength at 28 d was similar or higher for concretes with porous ashes exposed to drying than the reference concrete cured underwater. A significant improvement also at later ages, both in drying regime and in underwater curing, was obtained for concrete with RHA. The latter was most likely due to the pozzolanic activity of the RHA. Autogenous shrinkage was reduced in concrete with BTA compared to the reference concrete, while no negative effect on creep could be found.

The results presented here show that upcycling of ashes as functional additive for internal curing of concrete is a feasible way for improving the sustainability of concrete and reducing the environmental burden stemming from the incineration of waste.

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#### References

- Agarwal, S. (2006). "Pozzolanic activity of various siliceous materials." *Cement and Concrete Research* 36(9): 1735-1739.
- Bentur, A., S.-i. Igarashi and K. Kovler (2001). "Prevention of autogenous shrinkage in high-strength concrete by internal curing using wet lightweight aggregates." *Cement and Concrete Research* 31(11): 1587-1591.
- Bentz, D. P., P. Lura and J. W. Roberts (2005). "Mixture proportioning for internal curing." *Concrete International* 27(2): 35-40.
- Ghourchian, S., M. Wyrzykowski, P. Lura, M. Shekarchi and B. Ahmadi (2013). "An investigation on the use of zeolite aggregates for internal curing of concrete." *Construction and Building Materials* 40: 135-144.
- Wyrzykowski, M., S. Ghourchian, S. Sinthupinyo, N. Chitvoranund, T. Chintana and P. Lura (2016). "Internal curing of high performance mortars with bottom ash." *Cement and Concrete Composites* 71: 1-9.