TWO VARIANTS OF INTERNAL CURING OF RBA-BASED CONCRETE AND THEIR INFLUENCE ON THE PROPERTIES OF CONCRETE

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One of the progressive and currently rapidly developing methods for improving the properties of concrete with recycled aggregates is internal curing, which means the supply of curing water directly from the inside of the concrete. This article introduces two variants of internal curing of concrete with recycled brick aggregate (RBA) by pre-soaking process as a part of specific mixing course. The presented variants differ in the dosage of aggregates and water in the soaking process. Results of consistency, compressive strength, total water absorption capacity and capillary moisture content are analysed in terms of their change due to pre-soaking process, as well as due to time of processing the fresh concrete (90 minutes). The process of pre-soaking of RBA is beneficial for the consistency of concrete when evaluated immediately after mixing. For both the compressive strength and total water absorption capacity, the variant of pre-soaking is determining. Pre-soaking of only coarse RBA by amount of water derived of its absorbability (variant 1) gives better results than pre-soaking of all amount of aggregate by ½ of total mixing water (variant 2). The processing time 90 minutes does not adversely affect the compressive strength of concretes either with pre-soaked RBA or non pre-soaked RBA, even the strength increases slightly with processing time.

Keywords: *concrete, internal curing, recycled brick aggregate, fly ash, mixing course, discharge time*

1. Introduction

Sustainable waste management is at the heart of the circular economy and helps prevent the negative impact of waste on the environment and health. Construction and demolition waste (C&DW) is the largest waste stream in the EU by weight, reaching 800 million tonnes per year, i.e. approximately 36% of the total waste generated [1]. There is considerable scope for managing resource efficiency in managing this flow.

C&DW is a mixture of different materials that are practically easy to recycle, however the recycling rate for this waste is generally low. These are mainly materials such as so called "stony fractions", including both recycled brick (RBA) and recycled concrete aggregates (RCA). Experience suggests that one obstacle is the lack of awareness of possible procedures or tools to increase the recycling rate of C&DW [2]. Research activities on the application of recycled aggregates are rich and seek to define the rules for the production technology of concrete with these aggregates, as well as to clarify their impact on the properties of concrete. This need stems from proven knowledge about the nature of recycled aggregates and from the fact that these aggregates essentially reduce the quality of concrete [3-8]. Ways are being sought to correct this deficiency.

One of the progressive and currently rapidly developing methods of concrete improvement is internal curing. This means the supply of curing water directly from the inside of the concrete, where it is already included during its mixing in the mass of a particular carrier so that it does not increase the water/binder ratio of fresh concrete. At the same time, this water will be available to replace water lost by evaporation or autogenous drying [9]. While external curing water is applied at the surface and its depth of penetration is influenced by the quality of the concrete, internal curing enables the water to be distributed more equally throughout the cross section [10]. One way to incorporate the curing water into the concrete is to replace some of the normal aggregate with soaked lightweight aggregate [9, 11]. Currently, RCA and RBA are considered to be an efficient carrier of internal curing water as high porosity is their main feature. At the same time, this process would partially correct the initial negative impact of these aggregates on the concrete.

Sánchez-Roldán et al. [12] have studied the benefits of pre-soaked recycled coarse aggregate (RCA) on the properties of fresh and hardened concrete with this aggregate as replacement of natural coarse aggregate (NCA). Five pre-soaking methods was tested, differing in particular as regards the soaking time, the amount of water added to the mixture and the mixing time. They were then tested and compared with recycled concrete containing non-pre-soaked RCA and concrete with NCA. It was found that RCA pre-soaking only affects the consistency. The pre-soaking of RCA had little effect on fresh density, as well as it did not

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increase physico-mechanical properties of hardened concrete.

On the other hand, Elhakam et al [13] report the immersion of recycled aggregates in water up to 30 days as self-healing procedure, resulting in improved mechanical properties of recycled aggregates concrete especially for low cement content.

Mantun et al. [14] studied internally cured samples with three different percent replacements (15%, 20% and 25%) of stone aggregate with brick aggregate. The internally cured samples exhibited higher strength and less permeability and shrinkage as compared to their control counterparts under all adverse curing conditions considered in the study. Authors propose 20% partial replacement of stone aggregate with brick aggregate of 9.5 mm in size as a guideline for producing internally cured concrete under adverse curing conditions.

Feng Chen et al [15] presented results of recycled aggregate concrete (RAC) having from 20% to 100% replacement of natural aggregate by recycled brick aggregate (RBA) under four curing periods up to 28 days. They found that, the internal curing effect of RAC with a low RBA ratio is mainly reflected at the curing period of 14–21 days, and that of the RAC with a high RBA ratio appears at the curing period of 7–14 days. Authors also present that to ensure the performance of RAC while using as much RA as possible, a mixture with 40–60% RBA by volume is the most appropriate. However unlike other authors, they did not soak up the aggregate with any extra water before mixing the concrete, but they considered only an effective water coefficient.

This article introduces two variants of internal curing of RBA concrete by pre-soaking process as a part of specific mixing course. While standard concrete mixing involves mixing dry concrete components and then adding water together with a plasticizer, multi-stage mixing approaches consist of dividing the mixing cycle into stages, which differ in the sequence of addition of the individual concrete components. The aim is to form a grain cover in the mixing process, which has a beneficial effect on the properties of the concrete [16-19]. The presented variants differ in the dosing of aggregates and water in the soaking process. The significance of the results lies in the mixing procedures used, which belong to modern approaches, as well as in the experimental determination and evaluation of an aspect that is little studied - changing the properties of the concrete with the time of its processing. This aspect expresses the influence of the time of concrete transport up to its placement in the structure on its final properties.

2.Materials and methods

For concrete samples mixing, following materials were used:

- Natural aggregate (NA) - fraction 0/4
- Recycled brick aggregate (RBA): fractions 4/8 and 8/16
- Fly ash (FA): from the energy segment of the steel-making factory. The grain size of fly ash is $d_{(0.9)}$ = 95 µm.
- Cement: type CEM I 42.5 R according to [20] EN 197-1.

Admixture: polycarboxylate type of plasticizer (0.8%).

Properties of aggregates are given in Table 1.

The experiment is based on different mixing procedures, representing double and triple mixing and including two variants of internal curing of RBA by pre-soaking process. The aim of these mixing courses is to form a grain cover within the mixing process –the fly ash is considered to be helpful here. The mixing procedures are divided into steps differing in sequence of addition of individual concrete components and mixing time – see Figures 1 and 2. The difference also lays in a way of water dosage, with the aim of pre-soaking of coarse recycled aggregate. The procedure for mixing the reference mixture without pre-soaking the aggregate is shown in Figure 3. Table 2 shows the composition of concrete that was used for the experiment. The indicated amounts were the same for all mixing variants.

➢ *Pre-soaking Variant 1*

In this variant, only coarse aggregate was subjected to pre-soaking, while the amount of water for pre-soaking (W_{ab}) was designed on the basis of aggregate's absorption capacity. Following the principle of mixing course (see Figure 1), the amount necessary for the fly ash (W_{ef}) which was added in the subsequent step to form a grain-coating paste (w/b = 0.5) was added, too. In this way, the first batch of water can be expressed as follows: $W1 = W_{ab} + W_{ef}$, in which W_{ab} is water for absorption for coarse aggregates and W_{ef} is effective water, both defined above. The residual mixing water W2 can be expressed as: $W2 = W_{tot} – W1$, in which W_{tot} is total mixing water.

Table 1
Physical properties of aggregates

Aggregate		Density [kg/m³]	Bulk density [kg/m³]	Absorption capacity [%]	Void content [%]
NA	0/4	2650	1850	1.2	30.2
RBA	4/8	2050	1180	9.6	42.4
RBA	8/16	2150	1180	7.0	45.1

Table 2

Composition of concrete [kg.m^{-3}]

Cement	Fly ash	NA	RBA		Water		
		0/4	**4/8**	**8/16**	W_{ef}	W_{ab}	W_{tot}
323	56	898	208	510	190.0	48.9	238.9

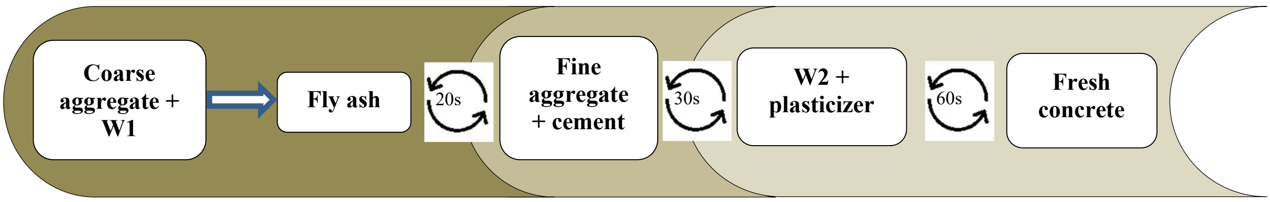

Fig. 1- 1st variant of pre-soaking.

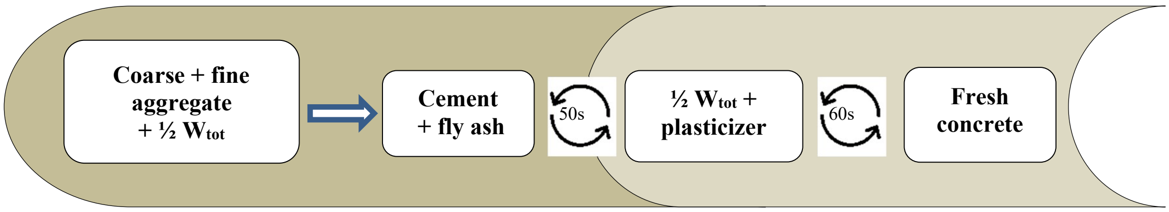

Fig. 2 - 2nd variant of pre-soaking.

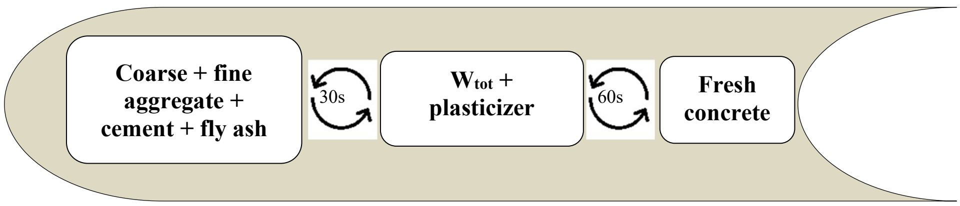

Fig. 3 - Standard mixing without pre-soaking.

➢ *Pre-soaking Variant 2*

In this variant, all of the aggregate entered mixing, and half of total mixing water W_{tot} was used to soak – see Figure 2.

➢ *Standard mixing without pre-soaking*

To compare the results of RAC with pre-soaked aggregate, the samples mixed in standard way without pre-soaking were prepared according to mixing course given in Figure 3.

After mixing by particular procedure, consistency was measured immediately after the mixing (0′), following by production of cube samples of 100x100x100 mm. To find out the impact of processing time on the properties of concrete, the same was done after 90 min (90′). While waiting for discharge and casting of the samples, each concrete mixture was re-mixed every 15 min. Three pieces of samples were prepared for each parameter and the presented results are the arithmetic mean of the measured values. The cubes were then cured under standard conditions up to the testing time. The following tests were performed after 28 days of hardening:

- consistency by slump test, according to [21] EN 12350-2;
- compressive strength (f_c) according to [22] EN 12390-3; moreover, the compressive strength was evaluated in terms of early-age time development; for this purpose, values after 2 days of curing were measured, too;
- total water absorption capacity (WA) by gravimetric method [23] STN 73 1316:1989;
- capillary moisture (water) content according to [23]: samples were dried to constant mass, and then one face of the specimens is immersed in water at a depth of 5–10 mm for 90 min.; capillary moisture content mc is characterized according to (1).

$$m_c = A_w . \sqrt{t} \qquad (1)$$

where:

m_c is capillary moisture content (kg/m^2),

A_w is water absorption coefficient (kg/m^2.s$^{1/2}$)

t is time (s).

Table 3

Results of properties (28-days of curing)

Parameter	Discharge time	Pre-soaking Variant 1	Pre-soaking Variant 2	No pre-soaking
Slump [mm]	0´	150.0	140.0	80.0
	90´	20.0	20.0	50.0
f_c [MPa]	0´	44.5	34.0	41.9
	90´	44.7	37.6	44.7
WA [%]	0´	8.7	9.2	9.0
	90´	9.0	9.0	8.8
m_c [kg/m^2.s$^{1/2}$]	0´	1.33	1.11	1.62
	90´	1.50	1.18	1.36

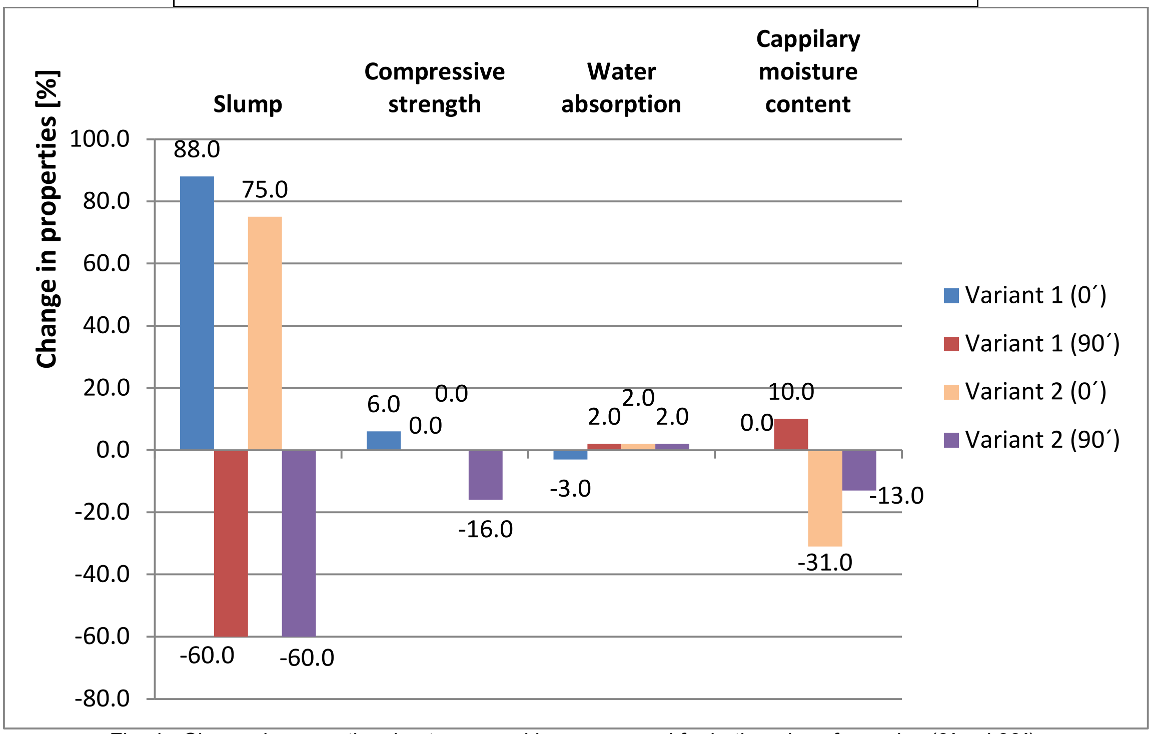

Fig. 4 - Change in properties due to pre-soaking, expressed for both series of samples (0´and 90´).

3.Results and discussion

Values of all tested properties for particular variants of pre-soaking are given in Table 3. The results are expressed in terms of the change (increase or decrease) caused by each of the pre-soaking variants compared to the non-soaked results, as well as the change (increase or decrease) caused by 90 minutes of processing time are illustrated in Figures 4 and 5, respectively. Table 4 gives the results of compressive strength after 2 and 28days of curing, while the expression of the change in values for particular variants of pre-soaking is illustrated in Figure 6.

The process of pre-soaking is beneficial for the consistency of concrete when evaluated immediately after mixing (0´). The consistency of the concrete with the pre-soaked aggregate is better than that of the non-soaked aggregate by 88% and 75% respectively. The finding is in line with that of presented by [12], suggesting that the workability of concrete made with recycled coarse aggregate improves with pre-soaking. However, this is not a case of consistency after 90 minutes, when standard mixing without pre-soaking gives better results of consistency and also the loss of consistency is “only” 37%, while the loss of consistency in variants 1 and 2 is 87% and 86% respectively.

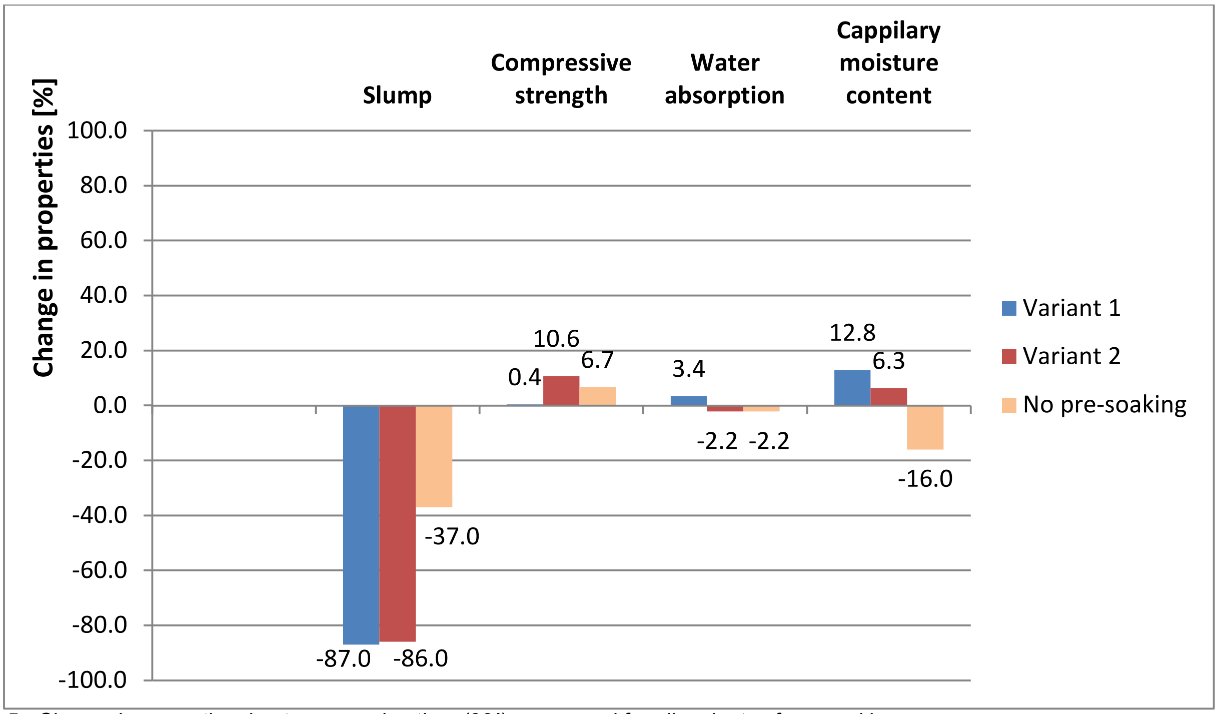

Fig. 5 - Change in properties due to processing time (90´), expressed for all variants of pre-soaking.

Table 4

Compressive strength after 2 and 28days of curing

Parameter	**Age of samples** [days]	**Discharge time**	**Pre-soaking**		**No pre-soaking**
			Variant 1	Variant 2	
Compressive strength * [MPa]	2	0´	22.4	19.9	20.0
		90´	21.5	22.3	21.3
	28	0´	44.5	34.0	41.9
		90´	44.7	37.6	44.7

** Note: the values are determined using samples of dimensions 100x100x100 mm; for possible comparison with standard results determined using 150x150x150 mm samples, it is necessary to convert these values, usually by coefficient 0.95.*

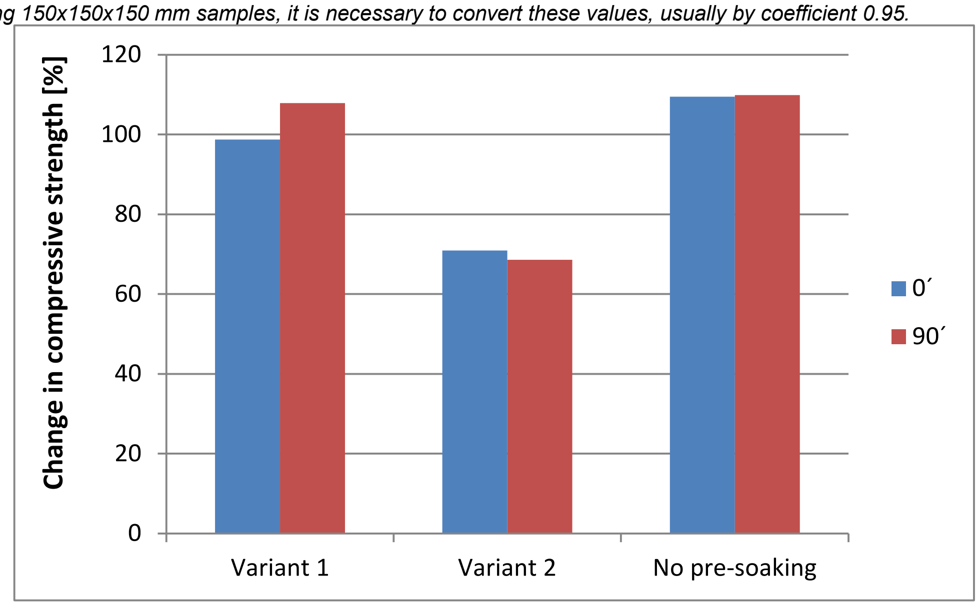

Fig. 6 - Development of compressive strength between 2 and 28 days of curing, expressed for both series of samples (0´and 90´)

According to results, the pre-soaking seems to be of little benefit to compressive strength, as well as to total water absorption capacity. An increase in compressive strength was only shown for samples made immediately after mixing the mixtures (0´) in variant 1 (6%), as well as a decrease in water absorption was observed only in this case (-3%). Preparing of concrete by variant 2 (pre-soaking of aggregates by ½ of total mixing water) causes decrease of compressive strength by 19% and 16% respectively. As for the compressive strength, our findings are closer to that of [12] than to those that present improvement by internal curing. The processing time does not adversely affect the compressive strength, even the strength increases slightly with time, for all concrete variants.

On the other hand, samples prepared by variant 2 achieved better results in capillary moisture content. This is lower than that of samples prepared without pre-soaking by 31% and 13.0% respectively. When tested immediately after mixing, also variant 1 gives an improvement in this parameter: decrease by 18%. This property is linked to the permeability of the concrete which seems to be positively influenced, as presented also by [14]. Concretes prepared with pre-soaked RBA seem to lose this feature with processing time; after 90 minutes, the m_c increase by 12.8% and 6.3% respectively. In contrast, m_c changes in positive way (decrease by 16%) for concrete prepared with no pre-soaked RBA.

When evaluating the development of compressive strength of the samples between curing days 2 and 28 (Figure 6), again the samples prepared without pre-soaking are the best. The strength of these samples increased by 109.5% and 109.9%, respectively. There is practically no difference between samples prepared immediately after mixing and samples prepared after 90 minutes. However, the strength for the samples prepared by variant 1 is only slightly lower (98.7% and 107.9% respectively), while the values of strength themselves in MPa are better. This variant provides the best values of compressive strength no matter when samples are produced.

4.Conclusions

- The process of pre-soaking of RBA is beneficial for the consistency of concrete when evaluated immediately after mixing.
- On the other hand, the loss of consistency after 90 min is higher for concretes prepared with pre-soaked RBA
- For both the compressive strength and total water absorption capacity, the variant of pre-soaking is determining. Pre-soaking of only coarse RBA by amount of water derived of its absorbability (variant 1) gives better results than pre-soaking of all amount of aggregate by ½ of total mixing water (variant 2)
- The processing time 90 minutes does not adversely affect the compressive strength of concretes either with pre-soaked RBA or non pre-soaked RBA, even the strength increases slightly with processing time.
- The process of pre-soaking is beneficial for capillary moisture content of concrete, especially when evaluated immediately after mixing. However, with 90 minutes of processing, concrete seems to lose this feature
- Taking into account the values of compressive strength, as well as their development between 2 and 28 days of curing, variant 1 of pre-soaking process is better than that of variant 2

On this basis, it can be stated that pre-soaking of aggregates may not have a clear impact on concrete parameters. For practical application, it is also important to take into account the fact that if the samples to be tested are made immediately after mixing the mixes (usually standard approach), different results will be shown compared to the samples produced from the mixture left in the time delay imitating the transport and processing of the concrete before it is placed in the mold.

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REFERENCES

[1] Sustainable Products in a Circular Economy - Towards an EU Product Policy Framework contributing to the Circular Economy. Commission staff working document, 2019, https://ec.europa.eu/environment/circulareconomy/ pdf/sustainable_products_circular_economy.pdf
[2] EU Construction and demolition waste protocol, 2016, https://ec.europa.eu/growth/content/ eu-construction-and-demolition-waste-prtocol-0 en
[3] N.D. Oikonomou, Recycled concrete aggregates. Cement and Concrete Composites, 2005, 27(2), 315–318.
[4] A.S. Abdel-Hay, Properties of recycled concrete aggregate under different curing conditions. HBRC Journal, 2017, **13**(3), 271-276.
[5] K. McNeil, T.H.-K. Kang, Recycled Concrete Aggregates: A Review. International Journal of Concrete Structures and Materials. 2013, **7**(1), 61–69.
[6] F.M. Khalaf, A.S. DeVenny, Properties of new and recycled clay brick aggregates for use in concrete. Journal of Materials in Civil Engineering, 2005, **17**(4), 456-464.
[7] M.K. Patel, C. Nayak, S. Patel, Use of recycled aggregates in concrete: A critical review. International Journal for Technical Education and Research Innovations, 2017, **1**(6), 1–6.
[8] F. Debieb, S. Kenai, The use of coarse and fine crushed bricks as aggregate in concrete. Construction and Building Materials, 2008, **22**(5), 886-893.
[9] P. Briatka, P. Makýš, Fresh concrete curing – 3. Saturated lightweight aggregate (in Slovak). Beton TKS, 2010, **3**, 40-45.

[10] D.P. Bentz, W.J. Weiss, Internal Curing: A 2010 State-of-the-Art Review. National Institute of Standards and Technology, U.S. Department of Commerce, 2011, 94.
[11] B. Kucharczyková et al. The porous aggregate pre-soaking in relation to the freeze–thaw resistance of light weight aggregate concrete. Construction and Building Materials, 2012, **30**, 761-766.
[12] Z. Sánchez-Roldán et al. Study of potential advantages of pre-soaking on the properties of pre-cast concrete made with recycled coarse aggregate. Materiales de Construcción, 2016, **66**(321), e076.
[13] A.AbdElhakam, A. Mohamed, E. Awad, Influence of self-healing, mixing method and adding silica fume on mechanical properties of recycled aggregates concrete. Construction and Building Materials, 2012, **35**, 421-427.
[14] T. Manzur, S. Rahman, T. Torsha et al. Burnt Clay Brick Aggregate for Internal Curing of Concrete under Adverse Curing Conditions. KSCE Journal of Civil Engineering, 2019, **23**, 5143–5153.
[15] F. Chen, K. Wu, L. Ren, J. Xu and H. Zheng, Internal Curing Effect and Compressive Strength Calculation of Recycled Clay Brick Aggregate Concrete. Materials, 2019, **12**, 1815.
[16] S. Uniyal, V. Aggrawal, Two-Stage Mixing Approach (TSMA) Versus Normal Mixing Approach (NMA) for Concrete in Terms of Compressive Strength and Carbonation Depth. International Journal for Scientific Research & Development, 2014, **2** (5), 721–725.
[17] V.W.Y. Tam, X.F. Gao, and C.M. Tam, Microstructural analysis of recycled aggregate concrete produced from two-stage mixing approach. Cement and Concrete Research, 2005, **35** (6), 1195–1203.
[18] R. Preetha et al. Effect of mixing methods in behavior of fly ash concrete. 2012. https://www.nbmcw.com/concrete/27659-effect-of-mixing-methods-in-behavior-of-flyash-concrete.html
[19] A. Sičáková, K. Urbán, The Influence of Discharge Time, Kind of Additive, and Kind of Aggregate on the Properties of Three-Stage Mixed Concrete. Sustainability, 2018, **10**(11), 3862-3862.
[20] EN 197-1: 2012 - Cement - Part 1: Composition, specifications and conformity criteria for common cement. European Committee for Standardization: Brussels, Belgium.
[21] EN 12350-2 (2020): Testing fresh concrete: Slump test. European Committee for Standardization: Brussels, Belgium.
[22] EN 12390-3: 2020 Testing Hardened Concrete. Part 3: Compressive Strength of Test Specimens. European Committee for Standardization: Brussels, Belgium.
[23] STN 73 1316:1989 Determination of moisture content, absorptivity and capillarity of concrete. Slovak Standards Institute: Bratislava, Slovakia.

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