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The Influence of Discharge Time, Kind of Additive, and Kind of Aggregate on the Properties of Three-Stage Mixed Concrete

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Abstract: Application of recycled aggregates (RA) for concrete production is limited due to their poor quality. While the environmental benefits of using the RA are well accepted, some unsolved problems prevent this type of material from wide application in structural concrete. The research and development of techniques which can minimize the adverse effect of RA on the concrete properties are highly requested. A specific mixing approach can also be helpful; here, mineral additives play a significant role for improvement of RA performance within the mixing process. However, delivery process can influence the homogeneity and uniformity of the concrete mixtures, resulting in negative effect on technical parameters. In this study, the impact of delivery time (0 min, 45 min, and 90 min) on the set of hardened concrete properties is presented while the three-stage mixing is used. Two kinds of additives—fly ash (FA) and recycled concrete powder (RCP)—were tested to coat the coarse fraction of recycled concrete aggregate (RCA) in the first step of mixing. For comparison, cement as coating material and natural aggregate instead the RCA were also used. The following parameters were tested after 28 days of setting and hardening: density, compressive strength, splitting tensile strength, water absorption capacity, and depth of penetration of water under pressure. Generally, 90 min of working with concrete mixtures left no significantly negative influence on tested characteristics. Based on ANOVA results, with prolonged discharge time, the changes in composition of the mixtures become less important for compressive strength, density, and water absorption.

Keywords: concrete; recycled concrete aggregate; mineral additives; three-stage mixing; discharge time

1. Introduction

Concrete of standard composition consists of three main constituents: water, cement, and natural aggregate. Supplementary cementitious materials (SCMs) and chemical admixtures are also commonly used to improve the concrete performance and to reduce the cost. The production of concrete consists of establishing a mixture proportion for concrete and then mixing the constituent materials to obtain a mixture with well-distributed components.

Many variables need to be considered to produce quality concrete; they can be considered in terms of constituent material variables and in terms of production parameters (mixing, transportation, and handling, as well as temperature). Briefly, constituent material variables include the characteristics of all components themselves, as well as how they interact. Because the aggregate accounts for the majority of concrete volume, its characteristics could likely significantly affect the characteristic of fresh and hardened concrete. Potentially influencing aggregate characteristics include maximum size of aggregate, gradation, shape and texture, specific gravity, and absorption. Because of the great effort to increase the use of recycled aggregates (RA), a lot of research activities can be followed worldwide. Now, the extent of the RA application for concrete production is limited due to its poorer quality. While the environmental benefits of using the RA are well accepted, some unsolved problems prevent this type of material from wide application in structural concrete. Recycled concrete aggregate (RCA) is composed of original aggregates and adhered mortar [1]. The major problems with the use of RCA in structural concrete are connected with the high water absorption, porosity, cracks, and lower strength. The presence of RCA and the porous nature of the old cement mortar affect the bonding between the RCA and cement paste when used in new concrete. That is why the poorer quality of RCA often limits its utilization [2].

Specifically, compressive strength and other properties of RCA-based concrete are influenced by the properties and amount of those aggregate in concrete. Several factors are important, including the water/cement (w/c) ratio, the percentage of coarse natural aggregate replaced with RCA, and the amount of adhered mortar on the RCA [3]. Also, other aggregate characteristics influence the quality of concrete, and some theories show that, independently of the water-cement ratio, the size, shape, surface texture, and mineralogy of aggregate particles themselves would influence the characteristics of the interfacial transition zone, thus affecting concrete strength [4].

The research and development of techniques which can minimize this adverse effect of RCA are taking place worldwide. These techniques are expected to consolidate the adhering mortar layer and reduce the porosity of RCA, thereby improving the interfacial bond between RCA and new cement paste in the new concrete. Except various cleaning methods (crushing, rubbing, sieving, and heat-, washing-, pre-soaking-, acid-, microwave-, etc., treatments) [5–7], the methods dealing with surface treatments of RCA (impregnation, coating…) are investigated, too [8–13]. A specific way to improve the properties of RCA-based concrete is by modifying the mixing process, in order to achieve the coating of RCA within the mixing. Double and triple mixing technologies are presented. While the standard mixing involves the pre-mixing of dry components first, following by addition of water with plasticizer, the principle of double/triple mixing lies in dividing the mixing process into the two/three steps, differing in the order and timing of concrete's components addition. This results in coating the aggregate in the first stage of mixing, thus improving its surface character. Various combinations are presented worldwide, generally resulting in improvement of final properties of concrete, when compared with normal mixing [14–21].

In current practice, concrete producers typically have established mixture proportions and mixing procedures with the objective of delivering a uniform concrete mixture to the job site. The mixing and delivery process can influence the homogeneity and uniformity of the concrete mixtures, resulting in a negative effect on technical parameters (workability and longer-term performance characteristics of concrete). Usually, the technical regulations state that discharge of the concrete shall be completed within 1.5 h after the introduction of the mixing water to the cement and aggregates or the introduction of the cement to the aggregates. Several studies present the results of prolonged mixing time on the properties of concrete. They are not consistent and include improvement, as well as worsening of results. Ravina [22] reported that the 7-, 28-, and 90-day compressive strength increased with increasing mix time up to 135 min for various mixtures. The author also noted the strength gain of these mixtures were linear. Kırca et al. [23] studied the 7- and 28-day compressive strengths as a function of mixing time at a constant mixing speed. The authors reported an increase in compressive strength as a function of mixing time and reported that the strength gain was a result of the loss of water due to evaporation, which led to a decrease in w/c ratio. The authors also reported that another possible reason for the increase in strength was that longer mixing times could have resulted in grinding of the cement particles, resulting in finer cement grains and more hydration. On the other hand, Trejo and Chen [24] report the results of laboratory-mixed concrete as exhibiting no significant reduction in properties (compressive strength, splitting tensile strength, modulus of elasticity, and modulus of rupture) when mixed up to 180 min at 8 rpm or less, while laboratory mixtures mixed at a mixing speed of 15 rpm exhibited reduced values. The field-mixed concrete exhibited significant reductions in compressive strength, splitting tensile strength, and modulus of elasticity after 120 min of mixing.

When using standard mixing technology, SCMs are often used in concrete. Most of the SCMs used today are byproducts of other industries. The use of these materials in Portland cement concrete provides many benefits, including making concrete more environmentally friendly, economical, and with improved characteristics and properties. The typical SCMs used today are fly ash, silica fume, and ground granulated blast furnace slag.

SCMs play a special role when used within the triple-mixing process. The basic principle of this technology by Kong [25] lies in following steps: (i) wetting the aggregate, using certain amount of mixing water following by additive, (ii) adding the cement, and (iii) adding the remaining mixing water together with plasticizer. Various authors deal consequently with adopting this method for extended investigation [26] or with some modification of this method. Lee et al. [14] applied "dry coating" where the coarse and fine aggregates were mixed first with melted sulphur to coat the aggregate surface, next the cement was added and dry-mixed with the coated aggregate and finally, fresh concrete was made by mixing with the water and superplasticizer. Urban and Sicakova [27,28] modified the order of RCA addition (the coarse fractions only are subjected to coating in the first stage of mixing) as well as design of water amounts for individual mixing stages.

However, practically all research papers provide experimental results obtained by measuring of samples prepared in the standard way, i.e., immediately after mixing. There is a lack (if any) of studies reporting the influence of mixing/discharge time on the properties of concrete when using triple mixing, as well as when using RCA. Thus, it is not clear whether extended mixing time will affect the structure of concrete obtained by triple mixing (coating of aggregate) with negative impact on concrete properties.

In this study, the delivery time, expressed by the technological parameter "discharge time", is the center of interest, and 0, 45, and 90 min after completion of the mixing process were considered as discharge times for testing. The influence on the set of hardened concrete properties is presented and evaluated. Samples were prepared by the triple mixing technique; here, the application of mineral additives plays a significant role. Two kinds of additives (fly ash and recycled concrete powder) were used to coat the coarse fraction of RCA in the first step of mixing. While the fly ash is considered worldwide to be a standard additive, the recycled concrete powder is not widely used; it represents a problematical part of recycled concrete. It was included in the experiment for environmental reasons to check whether it will be suitable to play the role of coating material in triple mixing. For comparison, cement as coating material and natural aggregate instead the RCA were also used. The following parameters were tested after 28 days of setting and hardening: density, compressive strength, splitting tensile strength, water absorption capacity, and depth of penetration of water under pressure. Two points of view are reflected in formulating the conclusions: kind of additive and kind of aggregate. The significance of changes in composition of mixtures on properties of hardened concrete was determined and proved by analysis of variance (ANOVA).

2. Materials and Methods

The main purpose of the experiment was to find out the impact of delivery time on the properties of concrete. Testing of this technological parameter is focused on the concrete samples, prepared with respect to sustainable materials principles: using alternative components (recycled aggregates, waste powdery additives) and using an advanced mixing technique for enhancement of the recyclability of those materials, as well as the durability of resulting concrete. Concrete samples were prepared by a specific mixing technique, together with customized compositions that investigate the role of additives, as described below.

2.1. Mixing

The actual mixing scheme, which represents the principle of triple-mixing, is given in Figure 1. The mixing method is typical, using mineral additives in the first stage of mixing to coat the aggregate. The compositions of concrete are customized with different additives. The choice of mixing process lies mainly in choice of recipes (amount of binder to coat the grains and fill the rest of voids between grains, amounts of water W_1 and W_2), and the time of addition of the fine aggregate.

The calculation of a particular mixture composition is based on the proposed thickness of the coating layer in the first mixing step: δ = 150 µm. The thickness of the coating layer was chosen based on Li el al. [9], who suggested 36–60 µm as typical thickness of interfacial transition zone (ITZ) in recycled aggregate concrete and thickness of 0.5 mm for covering whole ITZ. In this experiment, 0.15 mm thickness was chosen as being between those values.

The volume of paste for coating the coarse aggregate V_{cp} (m^3) was calculated using Equation (1):

$$V_{cp} = F * \delta \quad (1)$$

In Equation (1) above, F is the surface area of aggregates (m^2); δ is the thickness of layer (µm). The surface area of aggregate F [m^2] was calculated using Equation (2):

$$F = f * \frac{\rho_b}{\rho_p} \sum \frac{p_i}{0,1 * d_i} \quad (2)$$

In the equations above, f is the coefficient characterising the surface quality of aggregate (12 was intended for RCA); ρ_b is the loose bulk density of aggregate (kg/m^3); ρ_p is the particle density (kg/m^3); p_i is the amount of aggregate having average grain size d_i (%) and di is the average grain size of aggregates fraction (mm).

Next, the volume of binder paste for filling the voids between grains was calculated using the trivial absolute volumes equation and based on the density of individual components. The constant parameters were as follows:

- grain size distribution of aggregates: 0/4: 50%; 4/8: 15%, and 8/16: 35%,
- full replacement of natural coarse aggregate (4/8 and 8/16) by RCA
- water/binder ratio (w/b) = 0.5, both for the coating layer paste and for the filling paste.
- volume of paste for the coating layer (0.046 m^3) and volume of paste to fill the voids between grains (0.278 m^3).

Amounts of mixing water W_1 and W_2 consisted of two parts: the amount for absorption of the coarse aggregate, W_{ab} (calculated on the basis of aggregate's absorption capacity), and the amount available for coating/filling paste, effective water W_{ef} (calculated on the basis of amount of coating powdery material/cement, keeping w/b = 0.5).

The set of six different mixtures were tested while they were intended to achieve the S4–S5 consistency class according to [29], so it was necessary to adjust the amount of plasticizer for RCA-based mixtures.

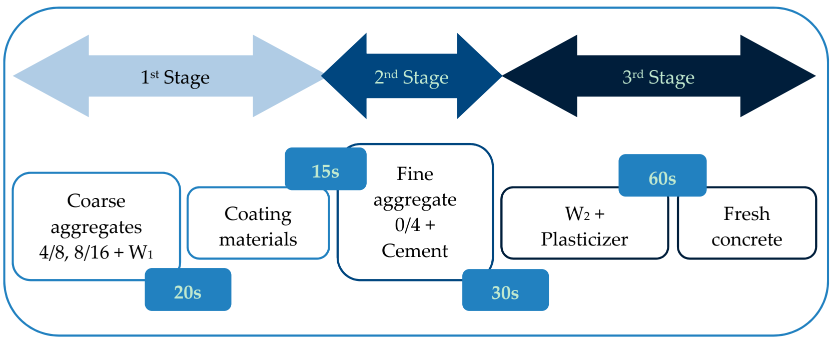

Figure 1. Experimental mixing procedure.

2.2. Materials

The characteristics of the materials used are as follows:

- **Aggregates:**
  - Fraction 0/4: natural aggregate (NA) is used for all recipes.
  - Fractions 4/8 and 8/16:
    - recycled concrete aggregate (RCA),
    - natural aggregate (NA).

Properties of aggregates are given in Table 1. Compared to NA, the RCA shows higher density, lower bulk density, and higher waster absorption capacity—this is in line with the character of material.

- **Coating materials:**
  - Fly ash (FA): from the energy segment of the steel-making factory from Eastern Slovakia. The original grain size of fly ash is $d_{(0.9)}$ = 95 µm.
  - Recycled concrete powder (RCP): this material was prepared with the idea of using fine portion of RCA which is otherwise difficult to recycle in concrete production. Particles under 125 µm were separated by sieving from the material that remained after the sorting of above mentioned fractions 4/8 and 8/16.

- **Cement:** type CEM I 42.5 R according to [30].
- **Admixture:** polycarboxylate type of plasticizer.

The chemical compositions of the coating materials are given in Table 2, demonstrating the different characteristics of the materials.

Table 1. Properties of the natural and recycled concrete aggregates.

Type	Fraction	Density (kg/m^3)	Bulk Density (kg/m^3)	Water Absorption Capacity (%)
NA	0/4	2650	1850	1.2
	4/8	2650	1850	1.0
	8/16	2650	1850	1.0
RCA	4/8	2200	1520	6.8
	8/16	2300	1520	5.3

Table 2. Chemical properties of cement, fly ash, and recycled concrete powder.

	SiO_2	Al_2O_3	Fe_2O_3	CaO	Others
			(%)		
Cement I 42.5 R	20.3	4.0	3.0	64.1	8.6
FA	51.6	23.1	7.8	4.1	13.4
RCP	31.1	8.7	2.7	12.4	45.1

2.3. Methods of Testing the Properties of Hardened Concrete

Six different mixtures were tested (see Table 3), which varied from each other by the kind of aggregate (RCA and NA) and by the kind of coating additives (FA, RCP, and CEM). Mixtures were tested according to mixing scheme given in Figure 1. Individual stages of mixing are illustrated in Figure 2a–d. To find out the impact of discharge time on the properties of concrete, the cube samples of different dimensions according to type of test were made in the following time intervals:

immediately after the mixing (0′), after 45 min (45′), and after 90 min (90′). The process is illustrated in Figure 2d–g. Three pieces of each sample were prepared for each parameter and the presented results are the arithmetic mean of the measured values. While waiting for discharge and casting of the samples, each concrete mixture was re-mixed every 15 min. The cubes were then cured under standard conditions up to the testing time.

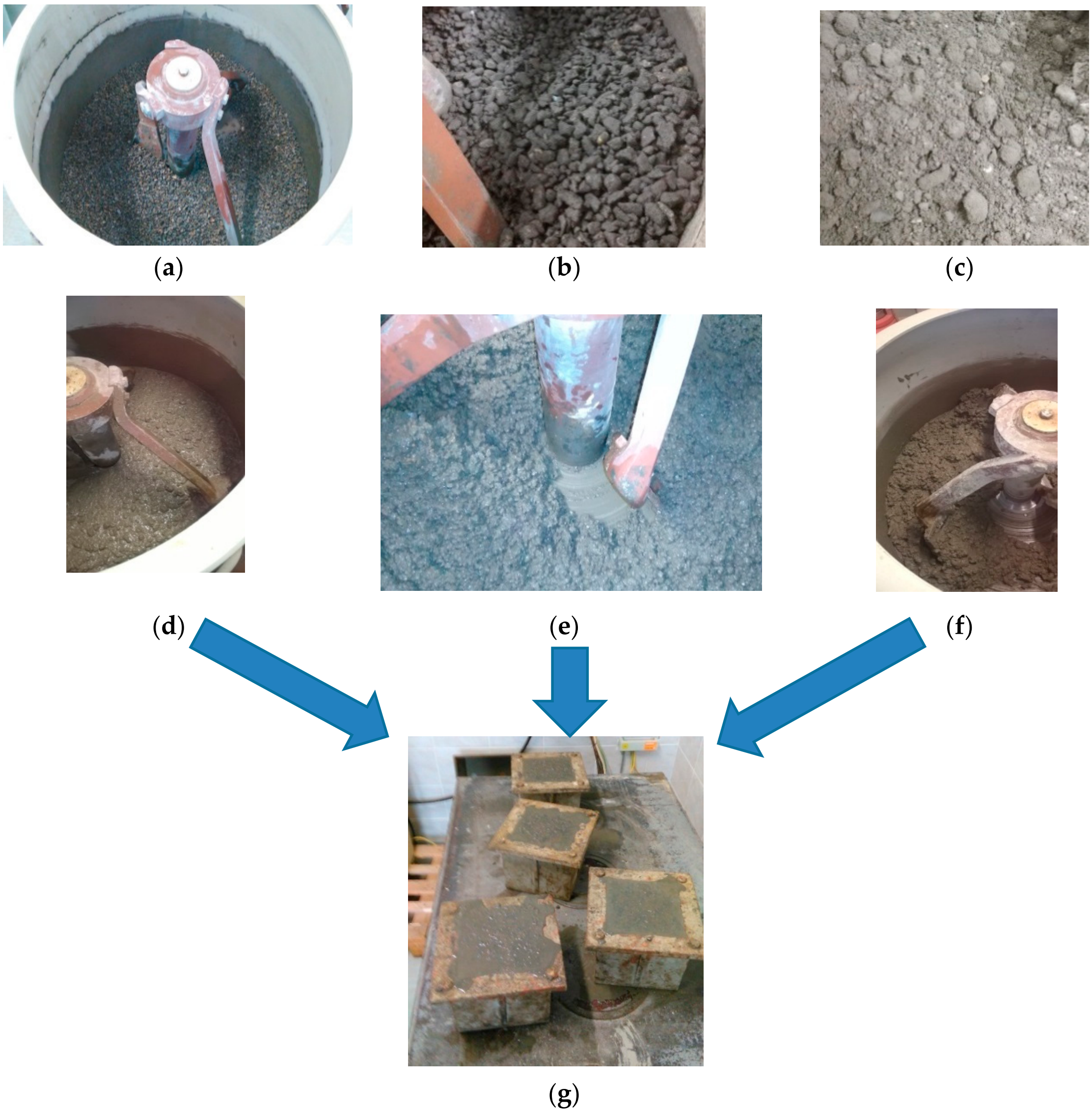

Figure 2. Illustration of individual stages of mixing and production of samples: (**a**,**b**) wet coarse aggregate and the consequent application of additive—coated aggregate in the first stage of mixing, (**c**) addition of cement together with fine aggregate—the second stage of mixing, (**d**) the ready mixed concrete with the rest of water and plasticizer—the third stage of mixing, (**e**) the mixture after 45′ after initial mixing, (**f**) the mixture after 90′ after initial mixing, (**g**) illustration of samples prepared after each of the discharge times.

The following tests were performed after 28 days of setting and hardening:

- density (ρ_v) according to [31], using cubes 100 × 100 × 100 mm.
- compressive strength (f_c) according to [32], using cubes 100 × 100 × 100 mm. To have a comparable level with the splitting tensile strength, the results were converted using index x_{cu} = 0.95 according to [33] (conversion of cube samples having the edge of 100 mm to that of having 150 mm).

- splitting tensile strength (f_s) according to [34], using cubes 150 × 150 × 150 mm.
- total water absorption capacity (*WA*) by gravimetric method [35], using cubes 100 × 100 × 100 mm.
- depth of penetration of water under pressure (*DP*) according to [36], using cubes 150 × 150 × 150 mm.

Table 3. Sample compositions.

Component (kg/m^{-3})		RCA—Coarse Aggregate			NA—Coarse Aggregate		
		RCA_{CEM}	RCA_{FA}	RCA_{RCP}	NA_{CEM}	NA_{FA}	NA_{RCP}
NA	0/4	898	898	898	896	896	896
	4/8	-	-	-	269	269	269
	8/16	-	-	-	627	627	627
RCA	4/8	224	224	224	-	-	-
	8/16	545	545	545	-	-	-
Paste to coat aggregates	Coating material	80	68	68	55	47	47
	Water W_{ef-1}	39.8	33.8	33.8	27.4	23.2	23.2
	Volume (m^{-3})	0.046					
Paste to fill voids	CEM I 42.5 R	310	310	310	336	336	336
	Water W_{ef-2}	155	155	155	168	168	168
	Volume (m^{-3})	0.278					
Admixture		2.5	2.5	2.5	2.7	2.7	2.7

3. Results and Discussion

3.1. Statistical Analysis of Results

The results of 28-day compressive and splitting tensile strength of concrete samples produced with different discharge times are shown in Table 4. The results of 28-day density, water absorption capacity, and depth of penetration of water are shown in Table 5. The significance of changes in composition of mixtures on properties of hardened concrete was determined by using analysis of variance (ANOVA). It was performed in two ways; first, all results were included to see the significance of all changes in composition; second, the significance of kind of coating material was considered separately, for this purpose, the results were grouped by kind of aggregate. Moreover, the significance was evaluated for 2 groups of samples: casted immediately after mixing (discharge time 0′) and casted after 90 min of initial mixing (discharge time 90′), to see when the mixtures are more sensitive to change in composition and whether the discharge time of concrete plays a role here. Changes in mixture composition were considered to have a significant effect on the properties if the p-value was found to be less than 0.05 (95% confidence level). Larger *F* values (comparing F_{crit}) also indicate that the variation of a mixture's composition causes a big change in the performance characteristics [37].

Table 4. Results of 28-day compressive strength and splitting tensile strength testing of samples produced with different discharge times, including standard deviation (%).

Sample	f_c—Compressive Strength (MPa)			f_s—Splitting Tensile Strength (MPa)		
	Discharge Time					
	0′	45′	90′	0′	45′	90′
RCA_{CEM}	35.2 (±0.1)	32.7 (±1.6)	33.1 (±0.8)	2.5 (±0.17)	2.8 (±0.12)	2.6 (±0.10)
RCA_{FA}	26.3 (±0.7)	27.7 (±1.0)	28.8 (±1.0)	2.2 (±0.20)	2.4 (±0.10)	2.2 (±0.20)
RCA_{RCP}	24.3 (±0.3)	21.1 (±0.9)	23.2 (±0.3)	2.2 (±0.10)	2.1 (±0.15)	2.0 (±0.00)
NA_{CEM}	35.2 (±1.1)	33.5 (±1.6)	33.1 (±2.4)	3.2 (±0.17)	2.9 (±0.17)	3.1 (±0.10)
NA_{FA}	36.3 (±0.8)	37.9 (±1.9)	39.6 (±0.3)	3.1 (±0.26)	2.9 (±0.17)	2.8 (±0.10)
NA_{RCP}	32.4 (±0.4)	30.9 (±1.4)	30.7 (±1.7)	2.7 (±0.17)	2.8 (±0.18)	2.4 (±0.17)

Table 5. Results of 28-day density, water absorption capacity, and depth of penetration of water of samples produced with different discharge times.

Sample	ρ_v—Density (kg/m^{-3})			WA—Water Absorption Capacity (%)			DP—Depth of Penetration of Water under Pressure (mm)		
	Discharge Time								
	0′	45′	90′	0′	45′	90′	0′	45′	90′
RCA_{CEM}	2220	2200	2190	9.1	9.1	9.4	30	25	30
RCA_{FA}	2190	2210	2210	10.3	10.3	10.2	40	30	35
RCA_{RCP}	2230	2180	2180	9.7	10.1	10.2	40	20	50
NA_{CEM}	2300	2280	2250	6.7	6.9	6.6	20	20	15
NA_{FA}	2320	2330	2340	7.3	7.0	7.1	25	25	30
NA_{RCP}	2330	2290	2260	7.5	7.2	7.5	25	15	10

The results of univariate ANOVA for evaluation of significance of all changes in mix composition on properties of hardened concrete properties are presented in Table 6. The findings point to significant differences in the mean values of properties, i.e., the composition of concrete mixtures has a significant effect on those properties (p-values < 0.05; F-values > here, F_{crit} = 3.106). The only exception is for depth of penetration of water under pressure with a discharge time of 0′.

Table 6. ANOVA results—significance of all changes in mix composition.

Property	Discharge Time 0′		Discharge Time 90′	
	F-Value	p-Value	F-Value	p-Value
f_c [MPa]	178.4484	7.87×10^{-11}	49.94545	1.28×10^{-7}
f_s [MPa]	16.02857	5.99×10^{-5}	29.1	2.59×10^{-6}
ρ_v [kg/m^{-3}]	133.7473	4.3×10^{-10}	48.0458	1.6×10^{-7}
WA [%]	349.9636	1.45×10^{-12}	278.6824	5.62×10^{-12}
DP [mm]	2.016	0.148368	3.280423	0.042596

Comparing statistical values between 0′ and 90′, some increase in F-values is visible (for f_s and DP), as well as decrease (for f_c, ρ_v, and WA). Thus, it is possible to assess whether the properties will become more sensitive to changing the composition of the concrete with the discharge time. If the F-value decreases, i.e., F_{crit} is approaching, and the effect of changing the composition of the concrete on its properties is diminished. In the opposite sense, the same is true for the p-value. On this basis, it can be said that with discharge time, the compressive strength, density, and water absorption become less sensitive to changes in the composition of the mixture, while the splitting tensile strength and depth of penetration of water become more sensitive.

The results of univariate ANOVA for evaluation of significance of kind of coating material on the properties of hardened concrete properties are presented in Table 7. Here, results are grouped by kind of aggregate (RCA and NA) and discharge time (0′ and 90′). The findings point to significant differences in the mean values of properties (p-values < 0.05; F-values > F_{crit} = 5.1433) in most cases. However, there are some exceptions here (labelled *) and it can be said that the kind of coating material has no significant effect on the splitting tensile strength of samples prepared directly after mixing (0′), and also on depth of penetration of water of practically all samples.

Table 7. ANOVA results—significance of change in kind of coating material.

Property	0′				90′			
	RCA-Based Samples		NA-Based Samples		RCA-Based Samples		NA-Based Samples	
	F-Value	*p*-Value	F-Value	*p*-Value	F-Value	*p*-Value	F-Value	*p*-Value
f_c [MPa]	522.1685	1.86×10^{-7}	17.87922	0.002966	132.9995	1.07×10^{-5}	21.28706	0.001885
f_s [MPa]	3.375 *	0.10421 *	4.84615 *	0.0559 *	16.8	0.003478	22.2	0.001687
ρ_v [kg/m^{-3}]	12.5	0.007251	13.54839	0.005958	2.08333 *	0.20555 *	72.51656	6.27×10^{-5}
WA [%]	108	1.97×10^{-5}	19.5	0.00237	27.42857	0.000958	18.3	0.002794
DP [mm]	0.57143 *	0.59270 *	0.75 *	0.512 *	0.88636 *	0.45997 *	28.67647	0.000849

* Results of *p*-values > 0.05 and F-values < F_{crit}.

3.2. Analysis of Results of Samples with Different Discharge Times

To evaluate the influence of discharge time, the percentage differences (increase/decrease) between the results of samples produced immediately after mixing (time 0′) and after 45′ and 90′, respectively, are expressed in Table 8. The values are organized depending on both the kind of aggregate and kind of coating material.

Table 8. Expression of the changes in properties (increase-decrease) over the discharge time, in terms of both the kind of aggregate and kind of coating material.

Coating Material	Time Span	ρ_v—Density (%)		f_c—Compressive Strength (%)		f_s—Splitting Tensile Strength (%)		WA—Water Absorption Capacity (%)		Depth of Penetration of Water under Pressure (%)	
		Aggregate									
		NA	RCA	NA	RCA	NA	RCA	NA	RCA	NA	RCA
CEM	0′–45′	−1	−1	−5	−7	−8	+10	+3.0	0	0	−17
	0′–90′	−2	−1	−6	−6	−4	+2	−1.5	+3.3	−25	0
FA	0′–45′	−0.5	+1	+4	+5	−4	+9	−4.1	0	0	−25
	0′–90′	+1	+1	+9	+9	−6	0	−2.7	−1.0	+17	−13
RCP	0′–45′	−2	−2	−5	−13	+5	−3	−4.0	+4.1	−40	−50
	0′–90′	−3	−2	−5	−5	−12	−6	0	+5.7	−60	+20

3.2.1. Density

The density of samples is higher for NA-based samples. All values fall into the range of standard-weight concrete according to [29]: 2000–2600 kg/m^{-3}. There is no significant change in density of concrete samples over the tested discharge times (Table 8). The increase/decrease of values does not exceed 3% (NA_{RCP}). Values after 90 min also do not cause a change of initial classification class (standard-weight concrete).

3.2.2. Compressive Strength

The highest compressive strength achieved was by the sample NA_{FA} for all discharge times. The lowest value reached was by the mixture RCA_{RCP}. Using cement as coating material seems to be very important for RCA—it improves the compressive strength significantly, comparing FA and RCP (e.g., in time 0′: 35.2 MPa versus 26.3 and 24.3 MPa, respectively).

After prolonged discharge time, a small negative effect on the compressive strength was found when aggregates were coated by both the cement and RCP (Table 8). The values are similar for both kinds of aggregates (NA and RCA)—generally up to 13%. When FA was used for coating, the prolonged mixing had a positive effect on compressive strength, again for both of aggregates (up to 9%). As for the negative effects, similar findings are also presented in other research works; Rahman et al. [38] present a decrease in 28-day compressive strength of self-compacting concrete after 90′ and 180′ while using standard mixing and without active admixture. Mohd et al. [39] also present a decrease in 28-day compressive strength of grade 30 normal concrete when the mixing time is increased up to 5 h. Gassman et al. [40] tested the effects of prolonged mixing on the hardened-state properties of controlled low-strength material and found that extending the mixing time beyond 30 min decreases unconfined compressive strength. On the other hand, Ravina [22] found that the compressive strength of concretes increases with mixing time up to 180 min for concretes with and without fly ash. In our experiment, only samples having FA showed an increasing tendency. Kamal et al. [41] present results of compressive strength testing for concrete based on brick recyclate aggregate with FA additive, while the set of samples was prepared at intervals of 15 min up to 135 min. With prolonged time, the differences between values were not significant and had no uniform tendency (increase or decrease), with coefficient of variation between 4.07–4.96 for 28-day samples and different NA replacement levels. Their results show that the compressive strength of concrete decreases when mixing time is increased.

3.2.3. Splitting Tensile Strength

The highest splitting tensile strength was achieved by sample NA_{CEM} with all discharge times. The lowest value reached mixture RCA_{RCP}. There is no significant difference between additives for RCA-based mixtures, while in the case of NA-based samples, the difference between coating by cement and by RCP is clear (e.g., in time 90′: 3.1 MPa and 2.4 MPa, respectively).

Evaluating the changes in splitting tensile strength over the discharge time (Table 8), prolonged discharge time brings changes up to 12%, both in positive and negative ways. Other research works mostly present negative impacts, like Rahman et al. [37], who present a decrease in 28-day splitting tensile strength of self-compacting concrete after 90′ and 180′ as well, while using standard mixing and no active admixture. Also, Trejo and Chen [24] present reductions in splitting tensile strength after 120 min of mixing, while using fly ash and blast furnace slag additives.

Unlike the compressive strength, the kind of aggregate influences how the splitting tensile strength changes—a decrease in strength in the case of NA was found, while in the case of RCA, positive changes were demonstrated when CEM or FA were used for coating.

3.2.4. Total Water Absorption Capacity

The water absorption capacity ranges between 7 and 10%. In the same group of samples, regarding the aggregate type, the values do not change significantly when changing the coating material.

After prolonged discharge time, in most cases of NA-based mixtures, the changes were positive (decrease in water absorption). When looking at RCA-based mixtures, mostly increased (max. 5.7% for RCA_{RCP}) or unchanged water absorption is visible. Rahman et al. [37] present an increase in water absorption by 7.99–9.61%. The best behaviour in this parameter was shown by samples with FA as coating material as it keeps the RCA-based mixture at a non-negative level not only after 45′, but after 90′ as well.

3.2.5. Depth of Penetration of Water under Pressure

Depth of penetration of water under pressure ranges between 20 and 50 mm, i.e., both groups of samples (based on RCA and NA) can be classified as "waterproof" according to National Annex [29] (here the limit is max 50 mm). Cement as coating material gives better results for both of kinds of aggregates.

Prolonged discharge time brings mostly a positive, or "no change" effect on the waterproofness of concrete. However, quite significant differences were found in values between 45′ and 90′ of mixing. We can see quite significant improvement of values after 45′ (excepting NA_{CEM} and NA_{FA} with no any change), while different changes are visible after 90′. Here, improvement and worsening have occurred. These changes cannot be systematically attributed to the type of aggregate or to the coating material—the worsening was determined for NA_{FA} 90′ (17%) and for RCA_{RCP} (20%). However, even the sample with the worst result (RCA_{RCP}: 50 mm) meets the requirement for waterproofness.

4. Conclusions

Two kinds of mineral additives—fly ash (FA) and the fine fraction of recycled concrete (RCP)—were used to improve the quality of concrete by coating of recycled concrete aggregate (RCA) with triple mixing technology. The cement (CEM) for coating, as well as natural aggregate (NA) instead of RCA, were investigated as control samples. The density, compressive strength, splitting tensile strength, total water absorption capacity, and the depth of penetration of water under pressure were evaluated for different discharge times (0, 45 and 90 min after mixing), with attention being paid to the type of aggregate and the type of coating material. The significance of changes in the composition of mixtures on the properties of hardened concrete was determined and tested by ANOVA.

The following conclusions can be formulated when summarizing the changes in the properties of concrete caused by prolonged mixing, i.e., over the discharge times (0′/45′ and 0′/90′):

- based on ANOVA results, with prolonged discharge time, the changes in composition of the mixtures become less important for compressive strength, density, and water absorption (properties are less sensitive to changes of mix composition), while for the splitting tensile strength and depth of penetration of water, the trend is opposite—changes in composition of the mixtures become more important.
- when evaluating the significance of kind of coating material separately, it was found to have a significant effect on density, compressive strength, and water absorption capacity of concretes based on both kinds of aggregate (RCA and NA), and of concretes prepared immediately after mixing and after 90′.
- FA has a positive effect, mainly on the changes in compressive strength and water absorption capacity, while RCP is promising for depth of penetration of water under pressure.
- as for the values of properties, the best results were achieved by using the control material (cement) to coat the aggregate. Both the FA and RCP typically cause deterioration of parameters, although this is not the case for all results. The NA_{FA} sample achieved better compressive strength than the NA_{CEM} sample. Except for the strength characteristics, there is no significant difference between the utilization of FA and RCP.
- the kind of aggregate influences the change in properties; application of RCA results in a comparable or positive impact for density, compressive strength, and depth of penetration of water under pressure. In the case of splitting tensile strength, it is only improved when it is coated with CEM or FA.
- samples with NA achieved generally better property results than those with RCA. However, the values of RCA-based samples obtained by the triple-mixing approach are technically sufficient for suitably specified practical applications.

Generally, after 90 min of working with concrete mixtures being prepared by a specific mixing approach, no significantly negative effect on the tested characteristics was observed. Alternative materials used in the experiment (recycled concrete aggregates, fly ash, and recycled concrete powder), when properly combined and mixed, seem to be promising for practical concrete production, not only from a standard technical parameters point of view, but also from technological one, taking into account the time of delivery of fresh concrete. Optimization of the discussed parameters and setting of exact conditions for valorisation of such alternative materials are under investigation.

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