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Analysis of compressive strength of concrete prepared by triple-mixing technology depending on both the discharge and curing time

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Abstract

Compressive strength of concrete having recycled concrete aggregate is influenced by the properties and amount of those aggregate. The worse quality of RCA can be eliminated by specific mixing approach. Practical mixing and delivery of concrete could affect the properties of ready concrete due to prolonged time. In this paper, both the fly ash and fine fraction of recycled concrete were used to improve the quality of concrete due to coating of RCA, while the triple mixing technology was applied for this purpose. The compressive strength is evaluated from two aspects: the curing time (2, 28 and 90 days) and discharge time (0, 45 and 90 minutes after mixing) with attention being paid to the type of aggregate and the type of coating material. When using triple mixing technology, prolonged discharge time brings only small effect on the compressive strength (up to 12%) both in positive and negative way, depending on kind of coating material.

Key words: concrete, triple mixing, recycled concrete aggregate, curing time, discharge time, compressive strength

1 Introduction

Concrete is unique and extensively conducive construction material by virtue of its excellent compressive strength, which is of the most important and useful properties of concrete. It is a composite material, consisting of aggregates enclosed in a matrix of cement paste. Concrete is the binder of cement, inert materials and water. In most structural applications, concrete is employed primarily to resist compressive stresses, which depends on plenty of factors like properties of ingredients, method of preparation, curing conditions etc. [1]

The environmental impact of production of the components of concrete (such as cement, coarse and fine aggregate) warrants close consideration. The scale of the problem makes it prudent to investigate other sources of raw materials in order to reduce the consumption of energy and available natural resources [2]. Unfortunately, the composition of these aggregates can vary substantially and consequently the varying properties have a significant influence on the properties of the concrete [3].

Thus the idea of using recycled concrete aggregate (RCA) in new concrete production appears to be an effective utilization of concrete waste. However, the strength of new concrete produced using recycled concrete aggregate needs to be evaluated before their use in structures [4].

Compressive strength of RCA concrete can be influenced by the properties and amount of recycled aggregate in concrete. Several factors are important, including the water/cement (w/c) ratio, the percentage of coarse aggregate replaced with RCA, and the amount of adhered mortar on the RCA [5]. The concrete strength is affected by the other aggregate characteristics, as well: size, shape, surface texture, grading (particle size distribution), and mineralogy, they influence concrete strength in varying degrees. 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 [6]. Chai [7] reported that the compressive strength of RAC decreased by 4 to 37% with increase in percentage replacement of coarse RCA. Jian Zhuang Xiaoa et al. also concluded in 2005 [8] that the compressive strength of recycled aggregate concrete generally decreases with increasing recycled aggregate contents. According to Patel et al. concrete made with recycled aggregate has a compressive strength (28 days) about 27% - 30% less than that of made with natural aggregates [9].

A significantly different approach was developed by the authors with the aim to improve the RCA properties directly during mixing in order to improve the properties of the whole concrete [10–13]. Different mixing methods (double mixing, triple mixing) are presented while their principle lies in dividing the mixing process in two/three steps, differing in the order and timing of concrete´s components addition. This in principle results in coating of aggregate in the first stage of mixing thus improving its surface character.

Various authors deal consequently with modification of basic triple mixing method given by Kong [14]. Lee et al. applied the “dry coating” where the coarse and fine aggregates were mixed for 15 s, then the melted sulfur was added and mixed to coat the aggregate surface for 120 s, the cement was added and dry-mixed with the coated aggregate for 30 s; and finally, fresh concrete was made after mixing with the water and superplasticizer for 60 s. [15]. Urban and Sicakova modified the order of aggregates 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 [16,17], Junak and Sicakova used geopolymer slurry to coat the RCA within triple mixing technology [18].

While several works dealing with the study of influence of prolonged mixing time on the properties of concrete are presented [19–21], authors of this paper did not find any study dealing with this technological aspect when double/triple mixing is sused.

In this study, the recycled coarse aggregate´s surface was coated with fly ash and fine fraction of recycled concrete to improve the quality of concrete. The triple mixing technology was applied for this purpose while RCA was coated in the first stage. The compressive strength is evaluated from two aspects: the curing time (2, 28 and 90 days) and discharge time (0, 45 and 90 minutes after mixing).

2 Material and methods

The main purpose of the experiment was to find out the impact of delivery time, which can be considered as prolonged mixing, on the compressive strength of concrete, while two specific aspects of concrete production are investigated: using the recycled concrete aggregate (RCA) and using the specific mixing technology. The triple mixing method (3M) given by Kong [14] was modified to be useful for purposes of the experiment and is described in Fig. 1. The mixing procedure differs in several aspects, like the sequence of adding aggregate (only coarse portions of aggregate are coated in the first stage of mixing), method of calculation of coating layer volume as well as way how the amounts of water W_1 and W_2 are considered. The amount of water in individual mixing steps is increased by a value corresponding to the absorption capacity of relevant, i.e. the “effective w/b ratio” is applied for both the paste to coat the RCA and the cement paste filling the voids between grains. The calculation of a particular recipe is based on the proposed thickness of the coating layer in the first mixing step: $\delta = 150$ µm. The volume of the paste for the coating as well as the volume of the paste to fill the voids between the grains is calculated by the Kennedy method. Subsequently the weight of both powdery materials - the coating additives and cement, is calculated on the base of their density.
Two kinds of additives are tested for the coating of RCA: fly ash (FA) and recycled concrete powder (RCP). As a control samples, mixture having the natural aggregate only, as well as mixture having cement as coating material were tested, too. Mix proportions are given in Table 1.

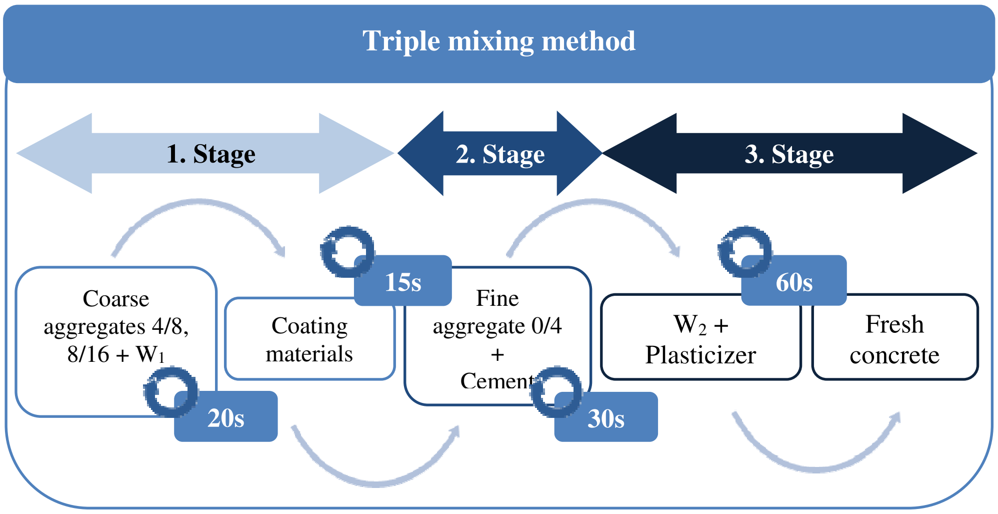

Figure 1: Experimental triple mixing procedure

The characteristics of 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) is used in this study. The 0/32 fraction of RCA was obtained from a company dealing with C&DW treatment (ENVIRONCENTRUM Ltd., Slovakia). Within the experiment, it was crushed and sorted to standard fractions.

- natural aggregate (NA)

- **Coating additives:**
  - Fly ash (FA): coming 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.
- **Admixture:** polycarboxylate type of plasticizer.

Table 1: Mix proportions of concretes

Component [kg]		RCA - coarse aggregate			NA - coarse aggregate		
		Coating material					
		CEM	FA	RCP	CEM	FA	RCP
		3-RCA_{CEM}	3-RCA_{FA}	3-RCA_{RCP}	3-NA_{CEM}	3-NA_{FA}	3-NA_{RCP}
CEM I 42.5 R		310	310	310	336	336	336
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	-	-	-
Material for coating		80	68	68	55	47	47
Admixture		2.5	2.5	2.5	2.7	2.7	2.7
Water	W_{ef-1}	39.8	33.8	33.8	27.4	23.2	23.2
	W_{ef-2}	155	155	155	168	168	168
	Total	232	226	226	203	198	202
w/b		0.5					

Six different samples were tested (see Table 1), which varied from each other by the kind of aggregate (RCA and NA) and by the kind of coating additives (FA, RCP and CEM). To find out the impact of discharge time on the compressive strength of concrete, the cube samples (100x100x100 mm) were made in the following time intervals: immediately after the mixing (0´), after 45 minutes (45´) and finally after 90 minutes (90´). While waiting for discharge and casting the samples, each concrete mixture was re-mixing every 15 minutes. The cubes were then cured in standard conditions up to the testing time. The standard test of compressive strength was executed after 2, 28 and 90 days of setting and hardening, according to [22].

3 Results

Compressive strength of concrete mixes in different curing and discharge times is shown in Table 2. Evaluating the results by "standard" way, meaning the strength of samples prepared immediately after mixing (time 0´), the highest compressive strength after two days of curing obtained sample 3-NA_{CEM} (19.4 MPa), while after 28 days it was 3-NA_{FA} (38.2 MPa) and after 90 days it was again sample 3-NA_{FA} (51.1 MPa). The lowest compressive strength reached mixture 3-RCA_{RCP} in all testing time; 11.7 MPa after 2 days, 25.6 MPa after 28 days and 31.4 MPa after 90 days.

There is no very important difference between samples based on RCA and corresponding samples based on NA as far as the cement only is used for coating the aggregate (3-RCA_{CEM} and 3-NA_{CEM}), looking at all discharge times. Once the additives (FA and RCP) are used for coating, the difference between the RCA and NA based samples is more significant, with the values of those based on RCA being worse. Comparing the kind of coating material, FA and RCP additives give worse results comparing the cement and FA gives better results than RCP.

Table 2: Compressive strength of samples in different curing and discharge times

Mixture	f_c - compressive strength [MPa]								
	Curing time								
	2d			28d			90d		
	Discharge time								
	0´	45´	90´	0´	45´	90´	0´	45´	90´
3-RCA_{CEM}	18.3	17.4	16.1	37.0	34.4	34.8	43.8	38.3	40.8
3-RCA_{FA}	13.4	13.4	12.7	27,7	29.2	30.3	37.8	40.2	39,0
3-RCA_{RCP}	11.7	10.6	11.4	25.6	22.2	24.4	31.3	28.9	29.2
3-NA_{CEM}	19.4	19.4	19.6	37.0	35,3	34.8	45.7	46.7	40.2
3-NA_{FA}	17,6	18.6	19.0	38.2	39.9	41.7	51.1	51.1	54.8
3-NA_{RCP}	15.7	15.9	16.5	34.1	32.5	32.3	39.4	39.3	38.6

- Analysis of change in results over the curing time

Changes in compressive strength of samples in different discharge times and depending on the setting and hardening time (expressed as difference between 90-day and 2-day values) are given in Table 3. It is evident that all of the tested samples had the same compressive strength time development (increase) while the rate of increase is quite significant. The curing time has positive effect on the compressive strength of all samples, regardless of the type of aggregate, discharge time or kind of coating material.

With only two exceptions (3-RCA_{RCP}-90´and 3-NA_{RCP}-45´), better effect is visible in the case of using FA and RCP for coating, comparing CEM. The well-known long-term strength development of pozzolanic materials has probably appeared here. Comparing the kind of aggregate, the rate of strength increase is higher for RCA in all cases, excepting 3-NA_{FA}-

0´and 3-NA_{CEM}-45´. In most cases, the progressive discharge time causes lower rate of strength increase, but the difference is not significant.

Table 3: Changes in compressive strength of samples in different discharge times and depending on the setting and hardening time

Sample	Increase in compressive strength 2d/ 90d [%]			Sample	Increase in compressive strength 2d/ 90d [%]		
	0´	45´	90´		0´	45´	90´
3-RCA_{CEM}	139	120	153	3-NA_{CEM}	136	141	105
3-RCA_{FA}	182	200	207	3-NA_{FA}	190	175	188
3-RCA_{RCP}	167	173	156	3-NA_{RCP}	151	147	134

- Analysis of change in results over the discharge time

Changes in compressive strength of samples in different times of setting and hardening and depending on the discharge time (expressed as difference between 90´values and 0´ values) are given in Table 4. Prolonged discharge time brings only small effect on the compressive strength (up to 12%) both in positive and negative way. It depends on the kind of coating material - positive effect is clear only for mixtures applying FA as coating material. Some difference is also evident looking at early (2-day) strengths and kind of aggregate; prolonged discharge time caused decrease of strength of samples based on RCA, while increase in strength of samples based on NA. Excepting this, the change in values caused by prolonged discharge time is very similar for all remaining mixes.

Table 4: Changes in compressive strength of samples in different times of setting and hardening and depending on discharge time

Sample	Increase/decrease in compressive strength 0´/ 90´ [%]			Sample	Increase/decrease in compressive strength 0´/ 90´ [%]		
	2d	28d	90d		2d	28d	90d
3-RCA_{CEM}	-12	-6	-7	3-NA_{CEM}	+1	-6	-12
3-RCA_{FA}	-5	+9	+3	3-NA_{FA}	+8	+9	+7
3-RCA_{RCP}	-3	-5	-7	3-NA_{RCP}	+5	-5	-2

4 Conclusions

The fly ash and fine fraction of recycled concrete were used to improve the quality of concrete due to coating of RCA, while the triple mixing technology was applied for this purpose. The cement for coating, as well as natural aggregate instead of RCA were involved into the experiment to test the control samples, too. The compressive strength is evaluated from two aspects: the curing time (2, 28 and 90 days) and discharge time (0, 45 and 90 minutes after mixing) with attention being paid to the type of aggregate and the type of coating material. Following conclusions can be formulated:

- when using triple mixing technology, the curing time has positive effect on the compressive strength of all samples, regardless of the type of aggregate, discharge time or kind of coating material,
- FA and RCP have better effect on the rate of increase the compressive strength with curing time comparing the cement; at the same time, FA gives higher values of compressive strength than RCP,
- there is no very important difference between samples based on RCA and NA as far as the cement is used for coating the aggregate; once the FA and RCP are used for coating, the kind of aggregate causes the more significant differences in compressive strength, with the values of those based on RCA being worse,
- prolonged discharge time brings only small effect on the compressive strength (up to 12%) both in positive and negative way, depending on kind of coating material - only fly ash brings the positive change in compressive strength with prolonged discharge time,
- excepting 2-day values, kind of aggregate does not influence the changes in compressive strength due to prolonged discharge time.

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