

The Effect of Mixing Technique and Prolonged Mixing Time on Strength Characteristics of Concrete [†]

Karol Urban ¹ and Alena Sicakova ^{2,*}

¹ Institute of Construction Technology and Management, Faculty of Civil Engineering, Technical University of Kosice, 04200 Košice, Slovakia; karol.urbanl@tuke.sk

² Institute of Environmental Engineering, Faculty of Civil Engineering, Technical University of Kosice, 04200 Košice, Slovakia

* Correspondence: alena.sicakova@tuke.sk; Tel.: +55-602-4275

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Abstract: The experiment aims to test the triple mixing (3M) technique to produce the concrete with recycled concrete aggregate (RCA). Then, the impact prolonged mixing, representing the influence of delivery and discharge time in praxis, is analysed by the change in strength properties. Both the 28-day compressive strength and tensile splitting strength are evaluated in two aspects: the prolonged mixing time (0, 45 and 90 min after initial mixing), and the mixing method (normal and triple). Prolonged mixing time brought both the positive and negative changes in strength characteristics however the worst difference between initial mixing (0') and 90' minutes of mixing was only 8.4% for compressive strength and 8.5% for tensile splitting strength.

Keywords: concrete; triple mixing; recycled concrete aggregate; mixing time; compressive strength; tensile splitting strength

1. Introduction

Recycled aggregates are produced by crushing and sorting an existing structure or parts thereof. Recycled aggregate from crushed concrete—recycled concrete aggregate (RCA)—is used quite often. As presented by [1,2], the properties of recycled aggregate are mainly influenced by its composition, affected by the quality of demolition, sorting, and recycling. RCA is a problematic material for concrete production, as it has a variable portion of original cement mortar adhering to the aggregate's surface, resulting in lower strength and higher water absorption. The quality is also affected by tiny cracks on the surface.

To improve the mechanical interface between the aggregate and the cement matrix, as well as the surface quality of RCA grains themselves, various mixing techniques are investigated, such as the two-stage mixing approach (double-mixing approach), and the three-stage mixing approach (triple-mixing approach), as described by [3,4]. The principle of dividing the mixing process into two/three steps lies in the different timings of concrete's components addition; the coating of aggregate occurs in the first stage in principle. Lot of modifications of basic models are investigated as for the order of dosage of components, and also as for the materials used, mainly the additives (fly ash, silica fume and others) [5–7]. As proposed by [8], these methodologies provide a possibility of improving performance of concrete made by using recycled aggregate, however need for further confirmatory investigations.

The mixing and delivery process can influence the homogeneity and uniformity of the concrete mixtures, resulting in negative effect on technical parameters (workability and longer-term

performance characteristics of concrete). Several studies present the results of prolonged mixing time on the properties of concrete.

To reduce the negative impact of RCA on the concrete strength, the own scheme of triple mixing procedure was used for experiment given in this paper. Samples were also prepared by normal mixing to compare the mixing techniques. The information whether the extended mixing time will affect the strength performance of concrete prepared by triple mixing negatively, is given as a useful technological parameter.

2. Methods and Materials

The experiment aims to test the specific, three-stage mixing technique, to produce the concrete with RCA. Then, the impact prolonged mixing, representing the influence of delivery and discharge time in praxis, is analyzed as a change in strength properties. In total, four series of mixtures were tested in the study: the control mix containing 100% of natural aggregate (density 2650 kg/m³, water absorption capacity 1.2%) and prepared by normal mixing, the mixture containing RCA (density of 4/8: 2200 kg/m³, density of 8/16: 2300 kg/m³, water absorption capacity of 4/8: 6.8%, water absorption capacity of 8/16: 5.3%) as a full replacement for natural coarse aggregate (density of 4/8 and 8/16: 2650 kg/m³, water absorption capacity of 4/8 and 8/16: 1.0%) and prepared by normal mixing, and the same two aforementioned mixtures prepared by triple mixing. As a coating material, two kinds of mineral powders were used: fly ash (coming from the energy segment of the steel-making factory from Eastern Slovakia, $d_{(0.9)} = 95 \mu\text{m}$) and cement CEM I 42.5 R. Both the 28-day compressive strength and tensile splitting strength are evaluated by changes in values [%], from two aspects: the prolonged mixing time (0, 45 and 90 min after initial mixing), and the mixing method (triple Figure 1, and normal Figure 2).

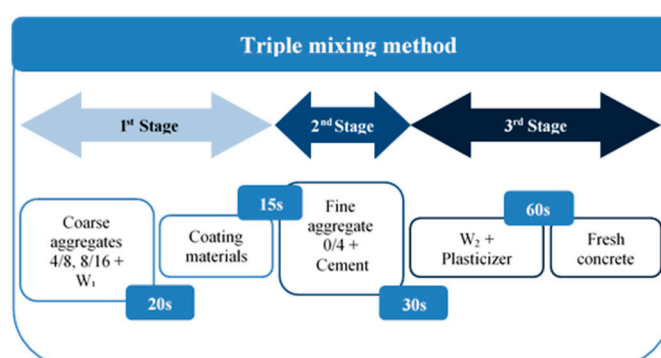


Figure 1. Experimental triple mixing procedure.

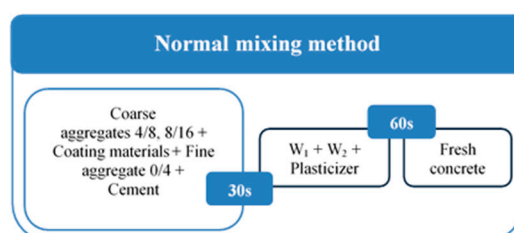


Figure 2. Experimental normal mixing procedure.

For each of mixture type, standard cubes of 100 × 100 × 100 mm were prepared for testing the strength characteristics. To find out the impact of prolonged mixing time, the samples were made in the following time intervals: immediately after the initial mixing (0'), after 45 min (45') and finally after 90 min (90'). While waiting for discharge and casting the samples, each concrete mixture was re-mixed every 15 min. Samples were demolded after 24 h and then stored under standard moisture and temperature conditions (95% RH and 20 ± 3 °C) until the corresponding testing time.

Compressive strength according to CEN EN 12390-3, and tensile splitting strength according to CEN EN 12390-6 were measured after 28 days of curing.

3. Results and Discussion

The results are evaluated by changes in values of both the compressive and tensile splitting strength [%] from two aspects: the mixing method (normal and triple), and the prolonged mixing time (0, 45 and 90 min after initial mixing). The aim is point to the changes in strength properties by various aspects; the values themselves were presented previously in [9,10].

3.1. Analysis of Change in Results in Terms of Mixing Technique

Changes in compressive and tensile splitting strength of samples depending on mixing technique (expressed as difference between results of samples prepared by 3M and by NM) are given in Table 1. Triple mixing brings improvement of compressive strength for samples RCA_{CEM} and NA_{FA}. The improvement is visible in all discharge times. The negative effect of 3M was observed in the case of samples RCA_{FA} and NA_{CEM}. The tensile splitting strength is affected in positive way using 3M in all discharge times, excepting sample RCA_{FA}.

Table 1. Changes in strength characteristics of samples prepared by triple and normal mixing.

Sample	Increase/Decrease in Strength Characteristics NM/3M [%]					
	Compressive Strength			Tensile Splitting Strength		
	Mixing Time					
	0′	45′	90′	0′	45′	90′
RCA _{CEM}	+48.6	+26.5	+23.8	+2.6	+22.2	+10.8
RCA _{FA}	−19.5	−17.5	−16.5	−12.5	−9.5	−5.4
NA _{CEM}	−13.8	−13.3	−11.5	+4.2	+4.2	+6.7
NA _{FA}	+1.3	+5.8	+19.5	+2.1	+2.2	+4.7

3.2. Analysis of Change in Results in Terms of Mixing Time

Changes in compressive and tensile splitting strength of samples depending on discharge time (expressed as difference between 90' values and 0' values) are given in Table 2. Prolonged discharge time brings both the positive and negative changes in compressive strength. Comparing the respective pairs of samples, the change over the mixing time is more positive when triple mixing is used (comparing normal mixing), except 3-RCA_{CEM}/NM-RCA_{CEM}. As for tensile splitting strength, the changes are up to 8.5%, while negative effect prevails; however, the change is less negative for 3M again.

Table 2. Changes in strength characteristics of samples over the mixing time, grouped according to kind of aggregate.

Increase/Decrease in Strength Characteristics 0'/90' [%]					
Sample	Compressive Strength	Tensile Splitting Strength	Sample	Compressive Strength	Tensile Splitting Strength
3-RCA _{CEM}	−6.0	+2.5	3-NA _{CEM}	−5.9	−4.0
3-RCA _{FA}	+9.4	0.0	3-NA _{FA}	+9.2	−6.0
NM-RCA _{CEM}	+13.0	−5.1	NM-NA _{CEM}	−8.4	−6.2
NM-RCA _{FA}	+5.5	−7.5	NM-NA _{FA}	−7.4	−8.5

4. Conclusions

Following conclusions can be formulated:

- Triple mixing brings improvement of compressive strength for samples RCA_{CEM} and NA_{FA} ; the improvement in tensile splitting strength was detected for all samples, excepting sample RCA_{FA} .
- Prolonged mixing time brought both the positive and negative changes in strength characteristics however the worst difference between initial mixing (0') and 90' minutes of mixing was only 8.4% for compressive strength (NM- NA_{CEM}) and 8.5% for tensile splitting strength (NM- NA_{FA}). Effect on strengths obtained from 3M is generally better.
- When focused on impact of prolonged mixing time, the RCA-based mixtures seem to be more favorable, as they retain the initial strength values better.

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