Periodica Polytechnica
Civil Engineering

62(4), pp. 1015–1020, 2018
https://doi.org/10.3311/PPci.11733

RESEARCH ARTICLE

Slump Loss of Concrete Based on RCA and Prepared by Specific Mixing Approach

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Received 21 November 2017; Revised 25 May 2018; Accepted 21 June 2018

Abstract
Concrete is a dynamic material and its consistency changes with time, having impact on technological processes at working site. It is expressed due to slump loss - the reduction in slump from the time of original batching to the point when concrete is discharged from a truck mixer. Two kinds of additives (fly ash and recycled concrete powder) were tested to find their potential to improve the performance of recycled concrete aggregate in concrete, while the principle of triple-mixing method was adopted. Slump loss was evaluated based on measurements taken at 0, 45, and 90 minutes after mixing. The kind of aggregate, as well as kind of powdery material for coating the coarse fractions play significant role for the slump loss. Mixtures with fly ash as coating material achieved the biggest slump loss for both types of aggregate. The recycled concrete powder is well acceptable having similar impact on the slump loss as the cement has. When the NA is changed to RCA, the slump loss is higher and depends on material used for coating.

Keywords
concrete, recycled concrete aggregate, triple mixing, slump loss

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1 Introduction

The slump loss of fresh concrete at construction site is one of the chief rheological properties considered to be responsible for the strength and durability aspects of concrete [1]. Concrete is a dynamic material and its consistency changes with time as mixing water is consumed through absorption by aggregates, cement hydration and evaporation. These factors are dependent on ambient conditions, types and combination of concrete materials as well as the total available water. Prudent control of the factors that affect concrete's workability requires an understanding of the factors, how they are interrelated, and what can be controlled by reasonable means. Mixture proportions, aggregate quantities, moisture contents, and admixtures are some of the factors that affect the rate and extent of slump loss that a ready mixed concrete producer can control. Concrete should achieve the required slump with consideration of the delivery time that can range from 45 to 90 minutes [2]. Prolonged mixing in a truck mixer accelerates stiffening of concrete so thus the rate of slump loss and the increased rate of the slump loss mostly brings about inconvenience, particularly when long hauling periods are involved as generally it is the case for ready-mixed concrete deliveries [1]. Slump is an important consideration for the contractor. The duration that elapses in the course of mixing, delivering, placing, compacting, and finishing operations of concrete is considered to be the chief parameter that affects the slump loss appreciably. The depletion of water in fresh concrete increases as the length of delivery time extends since the hydration of the cement and evaporation are directly related to elapsed time [1,3].

The recycling of construction and demolition waste (C&DW) as a source of aggregates for production of new concrete has attracted increasing interests from the construction industry. While the environmental benefits of using recycled aggregates are well accepted, some unsolved problems prevent this type of material from wide application in structural concrete. One of the major problems with the use of recycled aggregate in structural concrete is its high water absorption capacity which leads to difficulties in controlling the properties of fresh concrete [4]. Also as for recycled concrete aggregates (RCA), the most distinctive difference between the properties of the RCA and natural aggregate lies in water absorption, which is higher with RCA. The presence of cracks and the porous nature of the old cement mortar affect the bond between the RCA and cement paste when used in new concrete [5]. Also, this higher absorption causes the need for much more water for mixing and high slump loss rate depending on the elapsed time. These characteristics of RCA account for its low workability, strength, and durability [6-10].

The research and development of techniques which can minimize this adverse effect of RCA is taking place worldwide. These techniques are expected to improve the interfacial bond between RCA and new cement paste in the new concrete. Excepting the cleaning methods, the methods dealing with surface treatments of RCA (impregnation, coating ...) are investigated [10–12]. Shayan and Xu [13] reported the use of lime and silica fume to improve the surface properties of RCA and the results clearly demonstrated that the improved RCA can be used to produce 50MPa structural concrete with durability properties similar to those of natural aggregate concrete. Tsujino et al. [14] conducted experiments on using two types of surface improving agent, an oil-type and a silane-type, to improve the properties of recycled aggregates. Kou and Poon [5] tested the feasibility to improve the properties of RCA by using polyvinyl alcohol PVA – they found the 10% solution as being optimal for improvement of RCA to produce structural concrete with durability properties that are similar to those of natural aggregate concrete.

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 [15–18]. 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 characteristics.

Various authors deal consequently with modification of basic triple mixing method given by Kong [19]. Lee et al. applied the “dry coating” where the coarse and fine aggregates were mixed for 15s, then the melted sulfur was added and mixed to coat the aggregate surface for 120s, 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 60s [20]. 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 [21,22].

In this study, the slump loss as a technological parameter of fresh concrete is presented and evaluated. Two kinds of additives (fly ash and recycled concrete powder) were tested to find their potential to improve the performance of RCA in concrete, while the principle of triple-mixing method was adopted. Two points of view are reflected in formulating the conclusions: kind of additive and kind of aggregate.

2 Materials and methods

The presented investigation was intended to assess the slump loss of concrete mixture, while following specific aspects of composition and mixing are included:

- application of the triple mixing approach (3M)
- application of the recycled concrete aggregate (RCA)
- application of different coating materials: fly ash (FA) and recycled concrete powder (RCP)

Triple mixing method was intended as a way for improvement the surface quality of RCA directly during mixing the concrete while coarse part of aggregate only was subjected to this treatment. That is why the order of adding components has been specifically designed. Two kinds of powdery materials were tested for coating of RCA in the first stage of mixing: fly ash and recycled concrete powder. As a control mixture, concrete of standard composition was tested too, having natural aggregate (NA) and cement (CEM), while the cement meets both functions within the triple mixing: coating the aggregate and filling the voids between grains. The characteristics of the materials used are as follows:

2.1 Aggregates

Both the natural aggregates (sand and gravel) and recycled concrete aggregates were used in this study. As for RCA, he 0/32 fraction of was obtained from a company dealing with C&DW treatment (ENVIRONCENTRUM Ltd., Slovakia). Within the experiment, it was sorted to standard fractions (4/8 and 8/16). As for fraction 0/4, only NA was used in the experiment. The physical properties of the aggregates are shown in Table 1.

Table 1 Properties of natural and recycled 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

2.2 Materials for coating of aggregates

Fly ash (FA): coming from the energy segment of the steelmaking factory in eastern Slovakia. The original grain size of fly ash was $d_{(0.9)}$ = 95μm. The grading curve of FA is given in Fig. 1.

Recycled concrete powder (RCP): this material was prepared with the idea of using fine portions of RCA which is otherwise difficult to recycle in concrete production. Particles under 125μm were separated by sieving from the material that remained after the sorting of above mentioned fractions 4/8 and 8/16. The grading curve of RCP is given in Fig. 2 – $d_{(0.9)}$= 98μm. The Cl-content is 0.14%.

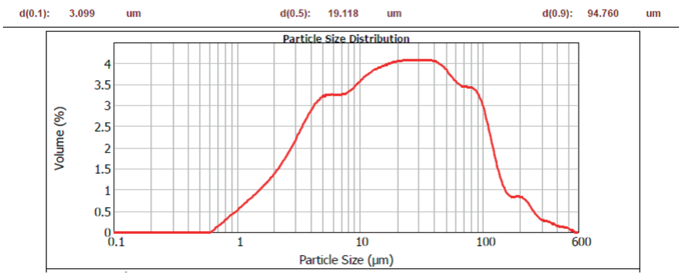

Fig. 1 The grading curve of FA

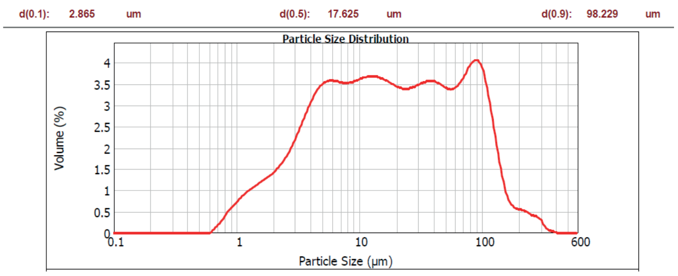

Fig. 2 The grading curve of RCP

Table 2 Chemical properties of CEM, FA and RCP

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

Cement (CEM): CEM I 42.5 R according to [23]. The chemical composition of the cement and coating materials is shown in Table 2.

Admixture: polycarboxylate type of plasticizer.

2.3 Design of concrete mixtures

For calculation the recipes of individual concrete samples, following assumptions were intended:

- coarse portions of RCA will only be of interest for testing and therefore they will be coated in the first stage of mixing,
- for coating, some alternative materials will be tested, keeping in mind the environmental aspect,
- concrete mixture should keep the basic limiting factors of composition by EN 206 [24]: min amount of cement (300 kg.m^{-3}) and max w/b(water/binder) ratio (0.5),
- because of specific character of RCA, design of concrete recipes should take into account the high water absorption and work with "effective w/b ratio",
- the thickness of coating layer forms a part of the concrete´s volume, so the amount of coating paste should be taken into account when calculating the total volume of binder. Thus, the volume of binder paste consists of volume of coating layer and volume of paste filling the rest voids between grains. A 150μm thickness is intended within the experimental program.

For above mentioned purposes, 3M approach was designed (see Fig. 3) such that the coarse aggregates were mixed (20 sec.) with addition of the first dose of water (W_1) to be soaked and wet. Next, the coating powder was added and agitated (15 sec.), in order to form the coating layer on the grain´s surface. Then, the cement and fine aggregates were added and mixed (30 sec.) following by the rest water (W_2) together with the superplasticizer (60 sec.).

For mixture composition, the volume of paste for coating the coarse aggregate was calculated, using following equations:

The volume of coating paste V_{cp} [m^3]:

$$V_{cp} = F * \delta \tag{1}$$

Where:

F is the surface area of aggregates (m^2),

δ is the thickness of layer (μm).

The surface area of aggregate F[m^2]:

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

Where:

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 (%),

d_i is the average grain size of aggregates fraction (mm).

Next, the volume of binder paste for filling the rest voids between aggregate was calculated using absolute volume approach. Here, the density of individual components is the input parameter. The constant parameters were as follows:

- grain size distribution of aggregates (for both the NA-based samples and RCA-based samples): 0/4: 50%; 4/8: 15% and 8/16: 35%,
- water/binder ratio (w/b) = 0.5, both for the coating layer paste and for the filling paste.

The composition of concrete mixtures is given in Table 3. Real amounts of mixing water W_1 and W_2 were adjusted taking into account the actual absorption capacity of aggregates, as described below.

The amount of water for the first stage of mixing (W1) consists of two parts: amount for absorption of the coarse aggregate – W_{ab-1} (calculated on the basis of aggregate´s absorption capacity) and amount creating the water layer on the surface for coating paste – effective water W_{ef-1} (calculated on the basis of amount of coating powdery material, keeping w/b = 0.5).

The second part of water (W_2) for the third stage of mixing also consists of two parts: amount for absorption of the fine aggregate – W_{ab-2} (calculated on the basis of aggregate´s absorption capacity) and amount for cement paste filling the voids between grains – effective water W_{ef-2} (calculated on the basis of amount of cement, keeping w/b = 0.5).

Generally, mixtures were intended to achieve the S4-S5 consistency class according to [24], so it was necessary to adjust the amount of plasticizer for RCA-based mixtures.

Table 3 Mix proportions of tested concretes

Components [kg]		Samples according to kind of aggregate and kind of coating material					
		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	-	-	-
Coating material		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	249.6	243.6	243.6	215.2	211.0	211.0
w/b		0.5					

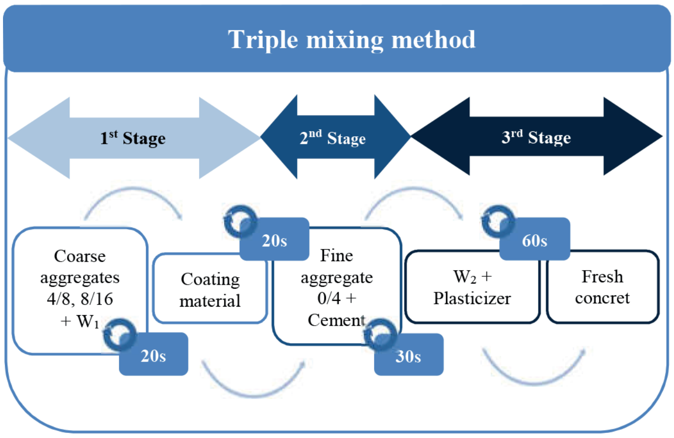

Fig. 3 Scheme of mixing course used in the experiment

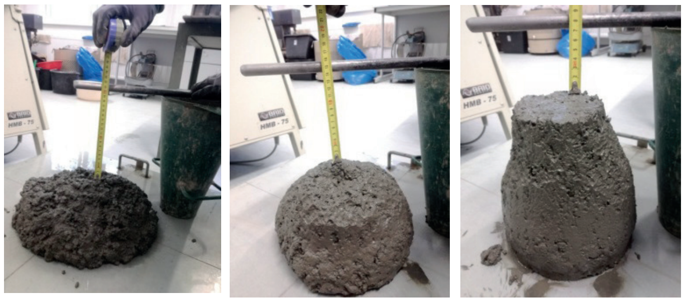

Fig. 4 Illustration of slump testing: sample 3-RCA_{FA} in 0, 45 and 90 minute, from left to right

Table 4 Results of slump test of RCA and NA based concrete mixtures prepared by triple mixing method

Mixtures of concrete	Slump [mm] Intervals of testing [min]			Slump loss 0'/90' [%]	Slump class change 0'/90'
	0'	45'	90'		
3-RCA_{CEM}	190	160	140	26	S4/S3
3-RCA_{FA}	200	140	70	65	S4/S2
3-RCA_{RCP}	135	120	90	33	S3/S2
3-NA_{CEM}	260	250	240	8	S5/S5
3-NA_{FA}	210	180	80	62	S4/S2
3-NA_{RCP}	220	210	200	9	S5/S4

2.4 The slump test

The standard slump test [25] was applied for testing the consistency of fresh concrete while it was tested in the following time intervals: immediately after the mixing (S_0), after 45 minutes (S_{45}) and finally after 90 minutes (S_{90}). While waiting for testing, each concrete mixture was re-mixing every 15 minutes. The results were obtained by repeating the test twice.

3 Results and discussion

Results of slump test of individual samples prepared by triple-mixing technology are given in Table 4. Here, also the slump loss is expressed as a difference between the values found at 0' and 90', as well as it is expressed through the change in slump class.

Slump loss is also illustrated in Fig. 4. Development of slump loss is presented in Fig. 5 for samples having RCA aggregate and in Fig. 6 for samples having natural aggregate.

Keeping the same principles in water amounts, the starting values of slump (time 0') were quite similar (190–220 mm) excepting mixtures 3-RCA_{RCP} (135 mm) and 3-NA_{CEM} (260 mm). The consistency of these mixtures lies in marginal positions of intended values.

Evaluating the influence of the aggregate type, mixtures having NA achieved generally higher slump than that of having RCA. This is the same principle as is presented for standard mixing; [26] present that the use of RCA decreased the slump and slump flow of concrete for both the normal and high workability concrete. They also achieved slump results revealing that a higher RCA content produced a lower workability what is credited to the physical characteristics of RCA particles. This can be linked to our experiment, where full replacement of fractions 4/8 and 8/16 was applied.

The change of consistency in time is clear in all cases; it also is similar as presented for standard mixing and agrees with [27] who tested the influence of different moisture states of RCA

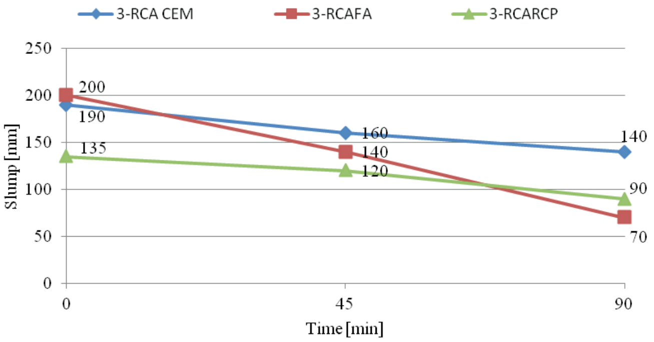

Fig. 5 Slump loss of concrete mixtures with RCA

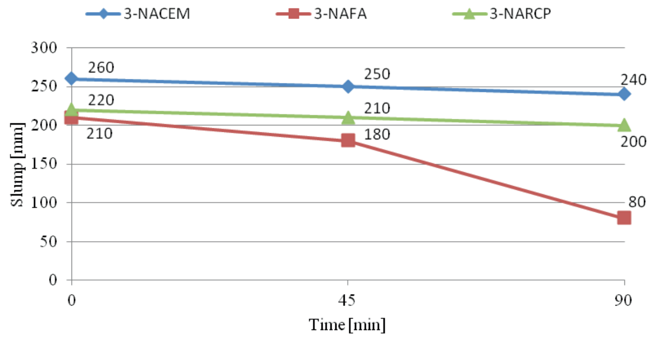

Fig. 6 Slump loss of concrete mixtures with NA

on concrete workability and found that the replacement of the natural coarse aggregate with coarse RCA at different moisture states caused significant rapid slump loss in the mix with time - even the samples having RCA in saturated state. The highest slump loss from 0' to 90' was achieved by the mixture with RCA coated by fly ash paste (130mm - 65%). Value of mixture with NA being also coated by fly ash is very similar (130mm–62%). Samples having cement as coating material (3-RCA_{CEM} and 3-NA_{CEM}) achieved the smallest slump loss within the relevant aggregate group: 50mm (26%) and 20mm (8%) respectively. Evaluating the influence of the aggregate type, mixtures having NA achieved generally lower slump loss than that of having RCA. For example, at time 0', the use of RCA instead of NA worsens the slump by 70mm (27%) in the case of coating with cement, by 10mm (5%) in the case of coating by fly ash paste and finally by 85mm (39%) in the case of coating by recycled concrete powder. It is clear, that using extra water for soaking the aggregates (W_{ab}) which was exactly the value of the aggregate´s absorption capacity is insufficient to achieve a consistent consistency development. However, instead of adding more water, here is a large area to optimize chemical admixtures.

4 Conclusions

Slump loss of concretes prepared by application of the triple mixing approach, by application of the recycled concrete aggregate as well as by application of different coating materials (cement, fly ash and recycled concrete powder) was tested. Slump loss was evaluated based on measurements taken at 0, 45, and 90 minutes after mixing.

The results obtained from the research can be summarized as follows:

- kind of aggregate, as well as kind of powdery material for coating the coarse fractions in the first stage of mixing play significant role for the slump values and slump loss,
- when the NA is changed to RCA, the slump loss is higher and depends on material used for coating:
  - the highest slump loss was achieved when aggregate was coated with RCP
  - the lowest one was achieved when aggregate was coated with CEM
- when evaluating the slump loss in time:
  - mixtures with fly ash as coating material achieved the biggest slump loss for both types of aggregate,
  - coating of coarse aggregate with cement is the most beneficial for keeping the consistency up to 90 minutes,
  - however, with the environmental point of view, the recycled concrete powder is well acceptable having similar impact on the slump loss as the cement has,

When using the fly ash as coating material, as well as when using high dosage of recycled concrete aggregate, an optimization of slump loss using the chemical admixtures seems to be necessary. For practical applications, different kinds of admixtures, distinguishing in chemical basis, should be verified to find, which one is appropriate; the admixture should be tailored for specific combination of aggregate, coating material and cement.

Acknowledgement

The project presented in this article has been carried out within the project supported by the European Union Structural funds: NFP 26220220051 “Development of progressive technologies for utilization of selected waste materials in road construction engineering” and project of Slovak Scientific Grant Agency VEGA (grant number 1/0524/18).

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