The impact of aggregates from recycling, discharge time and mixing technique on the consistency of concrete

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Abstract. Concretes prepared by the application of the triple mixing approach and by the use of both recycled concrete aggregate (RCA) and recycled clay brick aggregate (RBA) were tested in terms of loss of consistency. Fly ash was used to improve the performance of recycled aggregates during mixing — this is a specific aspect of the triple-mixing method. The slump test was performed immediately after mixing, as well as after next 90 minutes. The results were evaluated from the point of view of prolonged discharge time. Concrete consistency changes with time, having the impact on technological processes at construction site. Over the discharge time, the RBA-based concrete achieved the worst result — by 87% slump loss. Discharge time influenced the slump loss more favourably in the case of normal mixing and in the case of using natural aggregate (NA). The substitution of NA with both the RCA and RBA caused the slump loss turned worse, while RCA provided better results than RBA. However, the substitution of NA with both RCA and RBA resulted in more favourable change in the slump loss when concrete was mixed by 3M method.

1. Introduction

The mixing and delivery process can influence the homogeneity and uniformity of fresh concrete, resulting in a negative effect on the technical parameters (workability and long-term performance characteristics of concrete). 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 components as well as the total available water. Prudent control of the factors that affect concrete 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.

The slump loss of concrete mixture at a construction site is one of the fundamental rheological properties considered to be responsible for the strength and durability aspects of concrete [1]. 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]. The duration that elapses in the course of mixing, delivering, placing, compacting, and finishing operations of concrete is considered to be the main 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 cement and evaporation are directly related to elapsed time [1,3].

Several studies present the results of prolonged mixing time on the properties of concrete. They are not consistent and include the improvement, as well as the worsening of the results. Ravina [4] reported that the 7-, 28-, and 90-day compressive strength increased with increasing mixing time up to 135 min for various mixtures. The author also noted that the strength gain of these mixtures were linear. Kırca et al. [5] studied the 7- and 28-day compressive strength as a function of mixing time at a constant mixing speed. The authors recorded an increase in compressive strength as mixing time increased and reported that the strength gain was the result of the loss of water due to evaporation, which led to a decrease in w/c ratio. The researchers also stated 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 greater degree of hydration. On the other hand, Trejo and Chen [6] reported the results of laboratory-mixed concrete as exhibiting no significant reduction in the 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.

Based on volume, Construction and Demolition (C&D) waste is the largest waste stream in the EU – it represents about one third of all waste produced. Proper management of C&D waste and recycled materials – including the correct handling of hazardous waste - can have major benefits in terms of sustainability and the quality of life. But it can also provide significant benefits for the EU construction and recycling industry, as it boosts demand for C&D recycled materials [7]. Therefore, recycling of construction and demolition waste (C&DW) as a source of aggregates for the production of new concrete has attracted the growing interests of the construction industry.

Recycled aggregate (RA) is defined as aggregate resulting from the processing of inorganic or mineral material previously used in construction. When consisting mainly of crushed concrete it can be classified as recycled concrete aggregate (R_C), similarly for crushed clay brick – recycled brick aggregate (RBA) [8]. Shortly, the main technical problems of RA may be specified as follows [9, 10, 11, 12]:

- high content of cement paste/mortar,
- weak interfacial transition zones between original mortar and aggregate,
- high porosity / water absorption,
- high level of sulphates,
- high level of chlorides,
- impurity,
- poor grading,
- high variation in quality.

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 [13]. Higher absorption causes the need for much more water for mixing and a high slump loss rate depending on the elapsed time. These characteristics of RA account for low workability, strength, and durability of concrete [14-16].

To improve the unfavourable properties of recycled aggregates, the following methods of surface treatments of RA are investigated worldwide.

- impregnation / coating in advance before mixing the concrete [17-22]
- coating during mixing using specific mixing procedures [23-27]. For this purpose, mainly various Supplementary Cementitious Materials are used.

By the impregnation / coating process, the surface properties of recycled aggregates could turn to that of being more suitable for concrete production.
In this study, the slump loss as a technological parameter of fresh concrete being prepared with two kinds of recycled aggregate, is presented and evaluated. The principle of the triple-mixing method was adopted. Samples with natural aggregates, as well as samples prepared by standard mixing were also tested, being considered as the reference ones. The slump test was performed immediately after mixing, as well as after next 90 minutes. The results were evaluated from the point of view of prolonged mixing time, application of recycled aggregates instead of natural one, and the use of triple mixing instead of normal mixing.

2. Materials and methods
The presented investigations were intended to assess the slump loss of concrete mixture. The following aspects of concrete composition, mixing and testing were included:

- application of the recycled aggregates (RCA and RBA) in comparison with natural aggregate (NA)
- application of the triple mixing (3M) approach in comparison with normal mixing (NM)
- application of fly ash (FA) as a coating material
- assessment of the loss of consistency due to prolonged mixing time, by testing the slump 90 minutes after mixing, in comparison with the slump being measured immediately after mixing

2.1. Materials
The characteristics of the materials used in the study are as follows:

**Aggregates:** natural aggregates NA and recycled aggregates RA (RCA and RBA) of D_{max} = 16mm. As for RA, 0/32 fraction was obtained from a company dealing with C&DW treatment (ENVIRONCENTRUM Ltd., Slovakia). Within the experiment, RA was crushed and 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.

**Material for coating the coarse aggregates:** fly ash (FA) from the energy segment of the steel-making factory in eastern Slovakia. The original grain size was d(0.9) = 95μm. The chemical composition was as follows: CaO - 4.1%; SiO₂ - 51.6%; Al₂O₃ - 23.1% and Fe₂O₃ - 7.8%.

**Cement (CEM):** CEM I 42.5 R

**Admixture:** polycarboxylate type of plasticizer.

**Table 1.** Properties of natural and recycled aggregates.

| Type | Fraction | Density [kg/m³] | Water absorption capacity [%] |
|------|----------|----------------|-----------------------------|
| NA   | 0/4      | 2650           | 1.2                         |
|      | 4/8      | 2650           | 1.0                         |
|      | 8/16     | 2650           | 1.0                         |
| RCA  | 4/8      | 2200           | 6.8                         |
|      | 8/16     | 2300           | 5.3                         |
| RBA  | 4/8      | 2050           | 9.6                         |
|      | 8/16     | 2150           | 7.0                         |

2.2. Design of concrete composition and mixing technique
The compositions of concrete were designed keeping the limiting amounts of cement and water for the specific class of exposure, in accordance to the standard for concrete production (min 300 kg of cement and max w/c ratio = 0.5). The amounts of real mixing water (W₁ and W₂) were determined taking into account the actual absorption capacity of aggregates. The effective amount of water (Wₑf) needed for the paste was increased by the amount of water corresponding to the absorption value of aggregate. For calculation of the additive amount, the thickness of a coating layer was considered as δ.
The coating layer was considered as a part of the concrete volume, so the amount of coating paste was 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 voids between grains. The compositions were calculated taking into account the density of individual components to keep a constant volume of 1 m$^3$. For more details on the calculation methodology, see the articles [28, 29]. The compositions of concrete mixtures are given in Table 2.

The constant parameters of mixtures were as follows:

- the grain size distribution of aggregates (for both the NA-based samples and RA-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 triple mixing (3M) method was intended as a way to improve the quality of RA surface directly during mixing the concrete while the coarse part of the aggregate was only subjected to this treatment. Therefore, the order of adding components was specifically designed, see Fig. 1. For comparison, the same samples – recipes as given in Table 2 were mixed using the standard mixing procedure, see Fig. 2.

### Table 2. Mix proportions of tested concretes.

| Components [kg] | Samples according to the type of aggregate |
|-----------------|------------------------------------------|
|                 | NA | RCA | RBA |
| CEM I 42.5 R    | 336| 310 | 323 |
| 0/4             | 896| 898 | 898 |
| NA 4/8          | 269|-    | -   |
| 8/16            | 627|-    | -   |
| RA 8/16         | -  | 224 | 208 |
| Coating material - Fly ash (FA) | 47 | 68  | 56  |
| Admixture       | 2.7| 2.5 | 2.6 |
| Effective water | $W_{\text{ef,1}}$ | 23.2 | 33.7 | 28.0 |
|                 | $W_{\text{ef,2}}$ | 168 | 155 | 162 |

![Figure 1. Scheme of triple mixing procedure (3M).](image)
Figure 2. Scheme of normal mixing procedure (NM).

2.3. Testing the consistency
The standard slump test [30] was applied for testing the consistency of fresh concrete while it was tested in the two time sequences: immediately after mixing ($S_0$) and after next 90 minutes ($S_{90}$). Up to 90 minutes, the concrete mixture was re-mixing every 15 minutes. The results were obtained by repeating the test twice.

3. Results and discussion
The results of slump test of individual samples are given in 3. Here, the slump loss is also expressed as a percentage difference between the values found immediately after mixing ($S_0$) and 90 minutes after mixing ($S_{90}$), as well as it is expressed through the change in slump class according to [31]. To compare how the change of mixing method influences the consistency, the percentage differences are calculated and given in Table 3. The values are presented for mixtures according to the type of aggregate, as well as for both time sequences: 0 minutes and 90 minutes. Similarly, to compare, how the substitution of natural aggregate by RCA and RBA respectively influences the consistency, the percentage differences are calculated and given in Table 4. The values are presented for mixtures according to mixing method, as well as for both time sequences: 0 minutes and 90 minutes.

Table 3. Results of slump test and changes of slump in two time sequences.

| Mixtures of concrete | Slump [mm] | Slump loss [%] | Slump class change |
|---------------------|------------|----------------|-------------------|
|                     | $S_0$ | $S_{90}$ | $S_0 / S_{90}$ | $S_0 / S_{90}$ |
| NM-NA               | 220     | 180     | -18           | S5/S4            |
| NM-RCA              | 210     | 70      | -67           | S4/S2            |
| NM-RBA              | 80      | 50      | -38           | S2/S2            |
| 3M-NA               | 210     | 80      | -62           | S4/S2            |
| 3M-RCA              | 200     | 70      | -65           | S4/S2            |
| 3M-RBA              | 150     | 20      | -87           | S3/S1            |

Table 4. Change in consistency due to substitution of NA by RCA and RBA, respectively.

| Samples according to mixing method | Change in consistency [%] | NA/RCA | NA/RBA |
|-----------------------------------|---------------------------|--------|--------|
|                                   | $S_0$ | $S_{90}$ | $S_0$ | $S_{90}$ |
| NM                                | -5    | -61      | -64   | -72     |
| 3M                                | -5    | -13      | -29   | -75     |
The starting values of slump ($S_0$) are quite similar (200-220 mm) for both the NA and RCA-based samples, as well as for both mixing methods (NM and 3M). The slump values of samples having RBA are lower, while the difference is more significant when mixtures are mixed normally (NM - 80 mm). Different values for RBA were found despite the fact that the same principle in water dosage was applied for all kinds of aggregates: providing sufficient water to soak up the aggregate at the start of mixing.

The loss of consistency in time was noticeable in all cases; it is similar as presented for standard mixing and agrees with [32]. The researchers, presenting their results in [32], tested the influence of different moisture states of RCA 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. In the conducted tests, the highest slump loss from 0 to 90 minutes was achieved by the mixture with RBA (87%), while the lowest one (18%) was achieved by NA-based sample. As for mixing methods, the slump loss 90 minutes after mixing seems to be higher for 3M; only in the case of RCA the difference between NM and 3M is negligible.

Looking at Table 4, and evaluating the influence of the aggregate type immediately after mixing ($S_0$), it is clear that the use of RCA instead of NA worsens the slump only by 5%, while the use of RBA instead of NA worsens the slump by 64% in the case of NM and 29% in the case of 3M method. After 90 minutes, using of both the RCA and RBA instead of NA causes much higher change in consistency. This is in agreement with [33], presenting that the use of RCA decreases the slump and slump flow of concrete for both the normal and high workability concrete. They also achieved slump results revealing that higher RCA content caused lower workability, which is attributed to the physical characteristics of the RCA particles. This can be linked to our experiment, in which the full replacement of 4/8 and 8/16 fractions was applied. The difference between the effect of RCA and RBA was also described in [34] where authors present a tendency for slump to decrease as the mixing ratio of RBA increased.

In terms of mixing methods, changes in consistency in line 3M are smaller or insignificant, than that of the relevant values in line NM; this points to the advantage of 3M mixing in this sense.

4. Conclusion

Concretes prepared by the application of the triple mixing approach and by using both the recycled concrete aggregate and recycled brick aggregate were tested in terms of loss of consistency. The slump test was performed immediately after mixing, as well as after next 90 minutes. The results were evaluated from the point of view of prolonged mixing time, the application of recycled aggregates instead of the natural one, and the application of the triple mixing instead of the normal one. The results obtained from the research can be summarized as follows:

- the slump loss was detected in all evaluated situations – by discharge time, as well as by the incorporation of recycled aggregates into the concrete mixture
- over the discharge time, the RBA-based concrete achieved the worst result – by 87% slump loss
- discharge time influenced slump loss more favourable in the case of normal mixing and when the NA was used
- the substitution of NA with both the RCA and RCB caused the slump loss turned worse, while RCA provided better results than RBA
- the substitution of NA with both the RCA and RBA resulted in more favourable change in slump loss when concrete was mixed by 3M method
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