ASSESSMENT OF WATER REDUCING ADMIXTURE IN CONCRETE WITH RECYCLED AGGREGATES

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Summary

The research-program '*ValReCon20*' proved the possibility to replace 100 % of the coarse original aggregates with recycled concrete aggregates (RCA) in concrete mixtures in the strength class C25/30. An important consideration is that the W/C-ratio must be limited by use of water-reducing admixtures: superplasticisers. This article discusses the findings of a study on the impact on the workability of recycling concrete using a polycarboxylate based superplasticiser. The research is mainly focused on the time of addition of the superplasticiser and the soaking condition of RCA. It is concluded that not soaking the RCA results initially in more free water, coming from the extra water added to compensate the absorption, so that the superplasticiser is activated more slowly. The rate of activation of the superplasticiser and the amount of water are linked to each other.

Keywords: Water reducing agent, superplasticiser, workability, recycled concrete

1 Introduction

In Flanders an increasing amount of construction and demolition debris is being recycled into recycled concrete aggregates. Traditionally, the road construction industry is a major consumer of these recycled aggregates but due to a strong decrease of the number of new roads to be constructed, new markets for use of recycled aggregates must urgently be found. A possible sustainable solution is the use of recycled concrete aggregates in concrete applications as for house building. The ValReCon20-project has shown that coarse aggregates can be replaced by coarse recycled concrete aggregates in concrete of strength-class C25/30 provided that the W/C-ratio is limited to 0.5 %. [1] The use of a water-reducing agent is required to obtain a good workability of recycling concrete.

Recycled concrete aggregates are by their origin angular and have a rougher surface than crushed limestone aggregates. This affects the workability of recycling concrete mixtures. On the other hand, recycled concrete aggregates are porous due to attached mortar. [2] This results in a higher water absorption compared to natural aggregates. The higher water-absorption and the angular, rough shape of RCA lead to a decline of workability. This decline can be compensated by adding more water to the concrete mix, consequently leading to a higher W/C-ratio which in turn affects the compressive strength in a negative way. To enhance the workability of the recycling concrete mix it may be necessary to use a water-reducing agent. The RCA will not only absorb the added water but also the admixtures which are dissolved in it. Therefor it may be necessary to add the admixtures in a higher dosage to the mix. In this study the effect of superplasticizer (SP) on the slump of fresh recycling concrete is investigated.

2 Literature research

Superplasticizers are molecularly active substances which ensure dispersion of the cement particles once they come into contact with the cement particles. This leads to a better workability of concrete mixtures at a constant W/C-ratio. The surface of a cement particle contains free positive and negative electric charges. Opposite charges attract each other so that the cement particles start to cling together to form large flakes. Adding SP causes dispersion of the cement particles. This can be obtained by creating a uniform electrostatic load on the surface of the cement particles causing electrostatic repulsion between them. Cement particles are mainly negatively charged (C_3S). Therefore, SP is added which especially reacts with the positive charges on the cement (C_3A) thus creating a complete negatively charged surface of the cement particle. Another possibility is by adding SP which ensures that the cement particles do not come close enough to each other so that steric hindrance may occur. [3]

The latest generations of SP are polycarboxylates. These not only make use of electrostatic repulsion, but also create steric hindrance. Polycarboxylates are synthetic admixtures which consist of a long main chain to which side chains are connected. Therefore they called the comb-shaped SP. The main chain is formed by the polymerization of various vinyl monomers. The side chains consist of polyethylene oxides (polyethers) and are soluble. Thanks to a large choice of vinyl monomers and polyethylene oxides, an infinite range of polycarboxylates can be generated. [4]

The adsorbed agent alters the properties at the surface of the cement particle, and thus the interaction between the cement particle and the dissolved substances as well as the mutual interaction between the cement particles. Adsorbed polymers (SP) pass a negatively charged part on to the cement surface. This transfer leads to electrostatic repulsion between adjacent cement particles and contributes to an increased dispersion of the cement particles. In the case of polymer molecules with a higher molar mass, the steric hindrance will lead to an additional repulsion with a short range. The steric hindrance and the electrostatic force both contribute to the flowability of the cement paste. Admixtures on the basis of lignosulphonates, naphthalene sulphonates, poly-melamine-sulphonates include the charged group SO_4^{2-}. This creates an electrostatic repulsion. Admixtures on the basis of polycarboxylate have larger molecular masses, and less charged groups. Consequently, the dispersion obtained here is by steric hindrance. The cement particles cannot get close enough to form flakes due to the action of electrostatic repulsion and steric hindrance. [5]

2.1 Influence of admixtures on the hydration process of cement

Chemical admixtures can influence the cement hydration and the binding process in different ways. Admixtures may hinder the formation of a protective cement-hydration-

-layer on the cement particle and change its properties. Admixtures that are still in solution in the pores at the beginning of the acceleration period have an influence on the cement hydration process later on. [6]

The organic molecules of the chemically adsorbed admixture react at specific places. On the cement surface there are less reactive and reactive places. The present SO_4^{2-} ions, which are present in a relatively large extent in sulphonated SP, react preferably with the aluminates which are located at the cement surface. Therefore, in places where fewer aluminates are present, there will be less reaction. The specific admixture-cement interactions can have a profound influence on the cement hydration rate, starting at the beginning of the hydration process. Organic admixtures such as sugars and hydrogen-carboxylic-acid-ions such as Ca^{2+}, aid to come in solution by complex formation. On the one hand, complex formation reactions can increase the decomposition processes and the speed of reaction. A typical example is the sugar adsorption on C_3A. On the other hand, a greater concentration of ions in solution slows down the precipitation of insoluble hydrates (C-S-H). The great advantage of complex formation reactions is that their influence disappears when the admixture is consumed.

A third effect of the admixture during the cement hydration reaction is that, in the presence of organic molecules on the solid interface between cement and the solution, a hindrance may occur of crystal nucleation (transition from one molecule to another phase in order to be more stable), and of accumulation of reaction products. On the other hand, the presence of organic molecules can lead to structural changes in the morphology of hydration parts. The only thing that is not slowed down by the adsorption of admixture is the formation of ettringite. [6]

2.2 Absorption of recycled concrete aggregates

An important feature of recycling concrete is the water absorption of RCA. The range of the water absorption of RCA is 5 % to 10 % and thus considerably higher than the water absorption of broken limestone aggregates which is in the range of 0.5 % to 1 %. [1] [7] [8] [9] The increased absorption is due to the attached mortar on to the RCA. The mortar is formed by the sand, water, cement, and air. When using unsaturated RCA, extra water must be added to compensate the water that can be absorbed by the porous aggregates. This is to avoid affecting the effective W/C-ratio. If the recycled concrete aggregates are soaked and are saturated but surface dry, then no additional water is added. [10]

3 Research methodology

Tests are focused on measuring the workability of recycling concrete. First of all the water absorption of RCA is determined according to the standard EN 1097-6 [11] Initially, the percentage SP is varied to make a reference curve of the workability. The goal is to obtain a slump class S4 up to 100 minutes after the beginning of the hydration process of the concrete mixture has started.

The parameters that are varied are the duration of soaking the RCA and time of addition of the SP to the concrete mix. The time of addition of the SP is varied because the presence of C_3A has a large influence on the action of the SP. The time of addition is 0, respectively 5 and 10 minutes. The duration of soaking the RCA is 30sec., respectively 5 min and 15 minutes. Soaking during 30 seconds corresponds to a slight soaking of RCA, while 5 minutes of soaking gives RCA a behavior that corresponds to the behavior of dry limestone aggregates. [2] After 15 minutes of soaking in water RCA is regarded as saturated. Further, a comparison is made of the effect of adding SP in different recycling concrete mixtures.

The selected type of cement affects the SP. In this study CEM III A 42,5 N LA was used. The effectiveness of the SP depends on the ratio $C_3A/CaSO_4$. The higher the ratio is, the smaller the increase of the workability will be. This cement was chosen because of its relative low C_3A content. In a strong alkaline environment, the admixtures become chemically unstable so that the workability is not improved. Therefore a LA cement type was opted. [12]

In this study, a polycarboxylate-based SP was used. The main reasons for this are the molecular mass and the action which is dependent on the amount of hydrogen atoms in the mixture. The large molecular masse will ensure that the agent will be absorbed more difficult by the porous RCA.

At each time a new mixture was made, the same procedure was followed, the same equipment was used, the same amount of concrete was made of which a slump test was performed at 5, respectively 10, 20, 40, 60, 80, and in some cases 100 minutes after production of the mixture. At the same time as the slump tests were made, two test cubes were sampled. The test cubes were vibrated twice during 3 seconds. The wet density the fresh concrete was determined. At 28 days, the dry density and compressive strength of the test cubes was measured.

According to this procedure curves of the workability were drawn. In abscissa the mixing time is plotted and in the ordinate the value for the slump. By adjusting parameters, the effect of a given parameter on the operation of the SP is investigated.

The concrete mixtures used in this research consist of 49 % sand (0/4), 43 % recycled concrete aggregates (4/16) and 8 % recycled concrete aggregates (8/32). This combination obtained a suitable gradation for the skeleton of the mixture according the calculation method of Bolomey.

Each mixture is given a designation such as x %/y sec/z min where:

- x = percentage admixture [%];
- y = duration of soaking of RCA [sec];
- z = point of time of addition of SP to the mixture [min];

In this study the limit for workability was set as a slump between 160 mm and 210 mm (slump class S4). The aim was to achieve a workability in class S4 up to 100 minutes. This is the condition which can occur on site when concrete is put in place.

4 Results

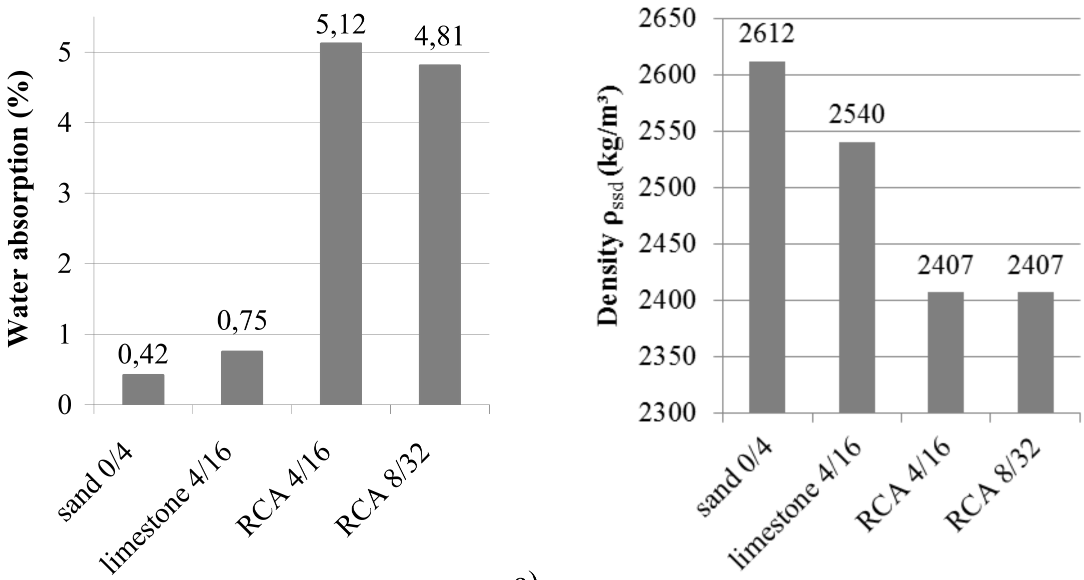
4.1 Water absorption by aggregates

To keep the effective W/C-ratio of each mixture on the same level, the water absorption of the aggregates was determined according the standard NBN EN 1097-6:2003. The measured water absorption and saturated surface dry densities ρ_{ssd} of the used aggregates are compared to limestone aggregate 8/16 shown in “Figure 1 (a) and (b)”. The higher water absorption of RCA is due to the pores in the attached mortar, which sucks up water by capillary action.

4.2 Variation of SP dosage

When administering a higher dose SP to the mixture, the workability will remain longer at the desired level. In the concrete mixtures 0 %/30 sec./0 min and 1,5 %/30 sec./0 min the used RCA have the same moisture content at the start of the mixing procedure. The initial moisture content of the RCA is 30 % higher in the mixtures 1 %/30 sec./0 min. and 2 %/30 sec./0 min.

As can be seen in “Figure 2”, the workability of the recycling concrete mixture made without added SP (curve 0 %/30 sec/0 min) declines rapidly. The slump drops from 15.9 cm after 5 minutes mixing to 10.9 cm after 10 minutes mixing. The RCA in this mixture was soaked for 30 seconds on beforehand, and the water absorption of RCA was compensated by adding an additional amount of water calculated from the water absorption of RCA and the amount of RCA in the mixture. The extra water was added at the mixing starting point. The strong decline of the workability which was noticed is due to the RCA still absorbing a lot of water during the first 10 minutes of mixing. Between 10 and 15 minutes, the absorption already happened and evaporation of water is gaining importance. In the research project “*ValReCon20”* was observed that the initial slump is higher when RCA are used in a dry state compared to when they are soaked on beforehand. [1]



a) b)

Fig. 1 *(a): Water absorption, (b): Density* ρ_{ssd}

When increasing the dosage of SP the workability curves shift to the right. It takes more time before the recycling concrete mixture reaches its highest slump. High doses may display a side effect of delaying the binding of the cement. In combination with blast furnace cement, the high dosage of SP side effects can be enhanced. [13]

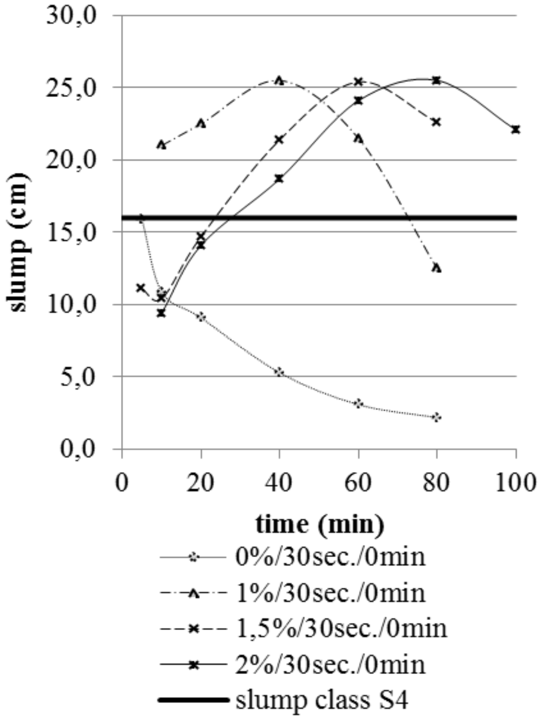


Fig. 2 *Influence of the dosage of SP on the workability of recycling concrete*

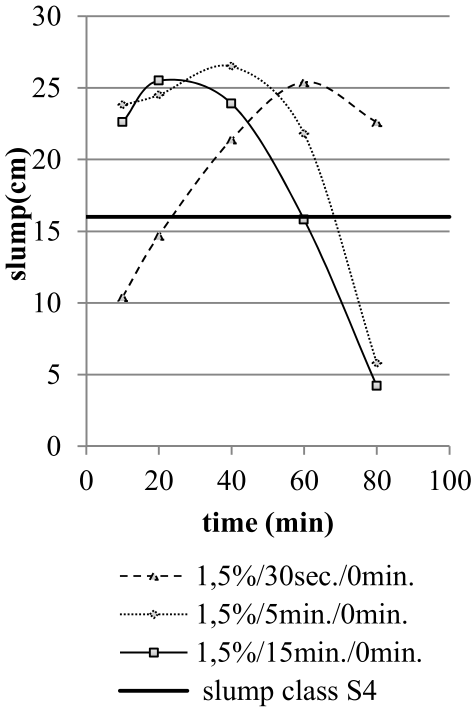


Fig. 3 *Influence of soaking RCA on the workability of recycling concrete*

4.3 Influence of soaking RCA

“Figure 3” illustrates the progress of the workability of recycling concrete made with RCA that was soaked during a certain time prior to mixing. The recycling concrete mix made with RCA that was soaked during 30 seconds shows an upward trend for the workability during the first 60 minutes. It took 24 minutes mixing until the required slump class S4 was reached. The workability is maintained over 90 minutes after the beginning of the hydration process. If the RCA are soaked during a longer time prior to making the concrete mixture, the curves showing the workability progress move to the left, indicating that a higher slump is achieved earlier. For mixtures with a longer time of soaking of RCA the required slump is achieved faster than the mixtures with shorter soaking time. The slump of recycling concrete mix made with 15 minutes soaked RCA drops below the required workability level S4 after 60 minutes of mixing, which is about 30 minutes earlier compared to recycling concrete made with RCA soaked for only 30 seconds.

“Figure 3” also illustrates that the speed at which SP acts upon cement is lower when RCA is soaked during a short time. The activity of SP is affected by the amount of water. If there is an extra amount of water added to the recycling concrete mix to compensate the water absorption of RCA, then the concentration of SP in the mixture will be reduced and the SP will act slower on the cement. When saturated RCA is used no extra water will be added and the SP will act faster resulting in a higher workability from the beginning on.

The SP gets into contact with the added water in the mixture. The hydrophobic parts of the SP will orient inwards, since they are repelled by the water. At the same time the hydrophilic particles are attracted by the water. In this way, spheres are formed in which air is enclosed. The speed, at which the cells come into contact with the cement, is partially determined by the reduction of the watercontent. The less water, the less repulsion, and so the hydrophobic parts can easily separate one from another and the spheres open up. Combined with the negative charge around the cement particles, this ensures that the spheres open completely. This situation arises due to the positive hydrophobic parts of the SP that are attracted to the negative charged cement and the negative hydrophilic parts wanting to repel to the cement but want attract to the water. Due to this reorganization the spheres will open and entrapped air will escape. By this arrangement, an optimal hydration of the cement is obtained in that the cement particles will repel each other. [13]

This arrangement accounts for the shift of the workability curves in “Figure 3”. By "free water" is meant the water that has not yet been absorbed by RCA. The more free water is present at the time of the addition of SP, the more of the water-reducing agent remains in solution. Therefor not all spheres will want to unfold resulting in a less active SP at that time. If RCA is soaked for 15 minutes prior to mixing, no extra water will be needed to compensate the water absorption, ensuring less free water present in the mixture at the time of addition of SP. Less free water in the mixture means that the spheres will unfold more easily resulting in a much more active SP.

Blontrock and Van Guyze [2] showed that the water absorption of RCA occurs mainly in the first 5 minutes. “Figure 3” shows clearly that, compared to recycling concrete made with just 30 seconds soaked RCA, the workability of recycling concrete made with 5 minutes soaked RCA has significantly increased. The RCA will be past most of its water absorbing capacity, so that amount of required free water in the mixture is reduced and the admixture becomes active faster.

“Figure 3” shows that SP is longer active in mixtures where RCA were not soaked. When RCA was soaked for 15 minutes, the workability dropped below the required level S4 after 60 minutes mixing time. When RCA was soaked during 5 minutes the workability of the recycling concrete remained above the level S4 up to 70 minutes mixing time and without soaking RCA the workability of the mixture stayed on the wanted level even longer. As a result of the hydration of the cement the alkalinity increases. During the hydration process water is chemically bound to the cement so that the number of hydrogen atoms in the mixture decreases. This results in a situation where the SP-molecules end up in a less water-rich environment, and -as stated before- the spheres will unfold easier thus more polycarboxylate molecules can be activated. In mixtures with 15 minutes soaked RCA the SP-molecules have initially been able to react more with the cement in a less water-rich environment. In the mixtures without soaked RCA the extra added water to compensate water absorption of RCA, the initially a larger amount of ‘available’ water causes the SP to remain longer in solution and is activated later. This also ensures a slower decline in workability.

Recycling concrete can be compared with 'light concrete' because RCA have a lower density than natural aggregates such as limestone of gravel. Light concrete has a larger demand for water making therefor it is preferred to soak the porous aggregates before mixing. [14]

4.4 Influence of the addition time

In “Figure 4” can be seen that 10 minutes after production of mixture 1,5 %/30 sec./0 min in which SP was added at the beginning of the mixing procedure, the workability is lower than in mixture 1,5 %/30 sec./5 min in which SP was added 5 minutes after the start of the mixing procedure. 10 minutes after production of mixture 1,5 %/30 sec./5 min. the SP was able to act during 5 minutes and the concentration of the C_3A was already been reduced. C_3A absorbs a large part of the available admixture and so when administering SP at the beginning of the mixing procedure more SP is needed to obtain the same workability as for mixtures where SP is added 5 minutes after the initial mixing. When the hydration process is in progress for a while, a layer of ettringite on the surface of the cement particles is being formed. [15] This reduces SP being adsorbed and SP has a better effect on the workability. For recycling concrete mixtures in which the addition of SP was done 10 minutes after the production, the workability is higher than in the other two mixtures. The workability stays longer on track for this mixture compared to the mixtures were SP was added 0 minutes and respectively 5 minutes after the beginning of the mixing procedure. In the recycling concrete mixture, in which after 5 minutes mixing SP was added, the RCA contained more water, partly coming from 30 seconds soaking prior to mixing and partly by absorption during the first 5 minutes of mixing, before SP was added to the mixture. Due to this soaking and the lower adsorption by the C_3A, the difference in workability between the mixtures 1,5%/30sec./5min. and 1,5%/30sec./0min is initially larger than with the workability of mixture 1,5%/30sec./10min. Just as in the case of the experiments with soaking RCA before mixing, the SP starts to work slower.

When looking at the points where the maximum workability is achieved, it can be noticed that the maximum workability of the mixture 1,5/30sec./10min is achieved after a longer time of mixing. The SP remains clearly longer active. When adding SP 10 minutes after mixing started instead of at the beginning, it appears that the recycling concrete remains 15 minutes longer in the workability class S4. This has to do with the fact that the SP didn't have the possibility in the first few minutes of the hydration process to react with the C_3A to form ettringite.

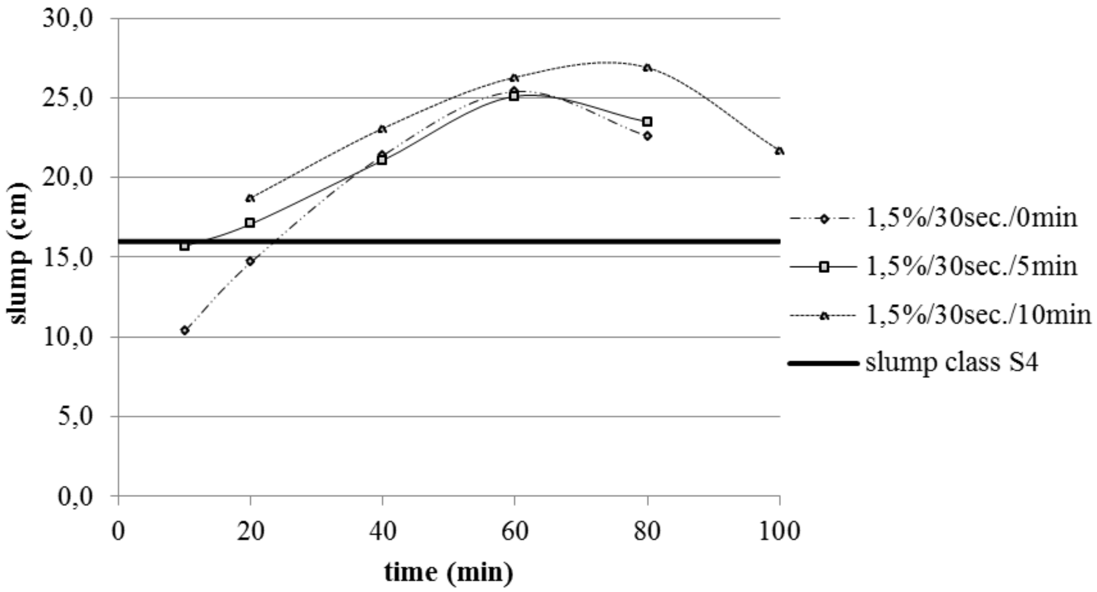


Fig. 4 *Influence of the addition time of SP to the recycling concrete mixture*

5 Sustainability aspects

Reaching a sustainable materials management is one of the goals that is set by the European Commission in its EU2020 strategy. One of the principles to reach this goal is to design and manage materials and products from a life-cycle perspective. Using RCA in recycling concrete fits well in this context providing this application complies with the quality standards and durability issues.

Just like in ordinary concrete mixtures, the W/C-ratio determines not only the workability of the fresh concrete but also its mechanical properties and durability. The water absorption and rough shape of RCA affects the workability of recycling concrete in a negative way. The workability of recycling concrete can be enhanced by adding more water but this increases the W/C-ratio up to an unacceptable level. Adding more water to the mixture to enhance the workability must subsequently be compensated by adding more cement to keep the W/C-ratio on an acceptable level (e.g. W/C < 0,50). This approach is far from sustainable: adding more water leads to more shrinkage and higher porosity which in turn leads to a lower durability (e.g. lower frost resistance), and using more cement leads to more embodied CO_2. Concrete with RCA can be made without enhancing the W/C-ratio, thus without adding more water and cement, by making use of a superplasticizer to achieve the required workability that lasts the desired time of delivery. The activity of the administered superplasticizer and the right time of administering must be investigated to determine the optimal and most economic dosage.

6 Conclusion

The study shows that recycling concrete is very sensitive to changes made to various parameters that are related to the workability. The moisture content of RCA at the beginning of the hydration process has a significant impact on the operation of SP. The lower the moisture content present in the RCA, the slower the SP increases the workability. The amount of water present in the mixture, and the activity of SP are related to each other.

The time of addition of SP has a significant impact on its operation. In the first 10 minutes of the hydration process the amount of C_3A has a significant impact on the operation of the SP. At first, the amount of C_3A is higher and so the SP acts during a shorter time. When SP is added later (> 30 minutes), it works more slowly in on the workability of the recycling concrete mixture.

Further investigations on the time of administering SP in recycling concrete mixtures are needed. Preliminary results in this study, which are not discussed in this article, showed that the addition of SP on the job site 60 minutes after the start of the hydration process can be economically advantageous.

Another topic that can be investigated is related to the type of concrete mixer and the mixing energy in relationship to the SP and the obtained workability. Superplasticizer becomes active more rapidly when adding more energy, but the workability also has to stay on a certain level during a sufficient long time.

RCA absorbs at least five times more water than natural aggregates. The amount mixing water to be added to the mixture when using soaked RCA is comparable to the amount of mixing water which would be needed if natural aggregates would be used. For un-soaked RCA, the water absorption must be compensated by adding an extra amount of water. This causes a delayed operation of SP in the recycling concrete mixture.

The best efficiency of the workability of the recycling concrete mixture is achieved after soaking RCA during 15 minutes prior to mixing and administering SP 10 minutes after the beginning of the mixing procedure.

References

[1] Boehme, L., Van Gysel, A.,Vrijders. J., Joseph, M.; Claes, J., *ValReCon20 – Valorisation of Recycled Concrete Aggregates in Concrete C20/25 & C 25/30*, Oostende: RecyCon – Luc Boehme, 2012.

[2] Blontrock. S., Van Guyze, G., *Opstellen van een voorbevochtigingscurve voor betonpuingranulaten,* KHBO, Oostende, 2010.

[3] B. CAE Nederland, *samenstelling deel 2, Hulpstoffen*, 25 Februari 2007. [Online]. http://www.uhsb.nl/?p=248.

[4] Weerdt, K. D., Reynders, D. , *Combining Plasticizers/Retarders and Accelerators*, 2006. [Online]. http://bwk.kuleuven.be/mat/publications/masterthesis/2006-de-weerdt_reynders-msc.pdf.

[5] Aïtcin, P.-C., Mindess, S., *Sustainability of concrete*, Oxon: Spon Press, 2011.

[6] Jolicoeur, C., Simard, M.-A. ,*Chemical Admicture – Cement Interactions: Phenomenology and Physico-chemical Concepts*, Cement and Concrete Composites, Elsevier, 1998, pp. 87–101.

[7] Abdelgadir Abbas, *Durability of recycled aggregate concrete designed with equivalent mortar volume method*, Cement & Concrete Composites 31, pp. 555–563, 2009.

[8] M. S. d. J. &. P. A. Gutiérez, *Study on the influence of attached mortar on the properties of recycled concrete aggregate*, Construction and Building materials, p. 6, 2009.

[9] Djerbi Tegguer, A., *Determining the water absorption of recycled aggregates utilizing hydrostatic weighing approach*, Construction and Building Materials 27, pp. 112–116, 2009.

[10] Malesev, M., Radonjanin, V., Marinkovic, S., *Recycled concrete as aggregate for structural concrete production*, Basel: MDPI, 2010.

[11] *NBN EN 1097-6: Tests for mechanical and physical properties of aggregates – Part 6: Determination of particle density and water absorption*., 2000.

[12] Palacios, M., *Adsorption of superplasticizer admixtures on alkali-activates slag pastes*, Elsevier, Madrid, 2009.

[13] Cools, H., Labaere, T., *Superplastificeerders in Kaolinietmix voor SCC*, Oostende, 2010, pp. 35–39.

[14] Belgische BetonGroepering , *Betonsamenstelling*, Betontechnologie, 5e editie red., Brussel, Belgische Betongroepering, 2009, pp. 259–309.

[15] Verstraeten, F., *Zelfverdichtend beton doorgelicht met ultrasone metingen*, Gent, Universiteit Gent, 2008.