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The influence of parent concrete and milling intensity on the properties of recycled aggregates

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Abstract

The C2CA concrete recycling process consists of a combination of smart demolition, gentle grinding of the crushed concrete in an autogenous mill, and a novel dry classification technology called ADR to remove the fines. The` main factors in the C2CA process which influence the properties of Recycled Aggregates or Recycled Aggregate Concrete (RAC) include the type of Parent Concrete (PC), the intensity of autogenous milling and ADR cut-size point. This study aims to investigate the influence of PC and intensity of the autogenous milling on the quality of the produced recycled aggregates. Three types of concrete which are frequently demanded in the Dutch market were cast as PC and their fresh and hardened properties were tested. After near one year curing of PC samples, they were recycled independently while the aforementioned recycling factors were varied. The effects of different recycling variables on the water absorption, density, crushing resistance and durability of produced recycled aggregates were investigated. According to the results, type of the parent concrete is the predominant factor influencing the properties of the recycled aggregates. Milling intensity was found to be effective on improving the properties of recycled aggregates coming from weaker parent concrete. The experimental results suggest that among various milling intensities, milling at medium shear and medium compression improves the overall quality of RA.

Keywords: C2CA process-Concrete recycling- Recycled aggregate- Recycled aggregate concrete- ADR.

Introduction

In the coming years, a strong increase of the amount of CDW is expected in Europe because of the large number of construction from the 1950s which are closing to their end of life [1]. End of life concrete is known to be the heaviest component of the CDW. Considering the fact that public and private sectors have become aware of the urgency and importance of CDW recycling, the European Commission has taken initiatives towards sustainable treatment and recycling of CDW. In this regards, a novel concrete to concrete recycling process (C2CA) is developed within a European project with the full title of “Advanced technologies for the production of cement and clean aggregates from construction and demolition waste”. C2CA process aims at a sustainable and cost-effective system approach for recycling of high-volume EOL concrete streams into prime-grade aggregates and cement [2].
Fig. 1 shows the C2CA process in brief. The technologies considered are smart demolition to produce crushed concrete with low levels of contaminants, followed by mechanical upgrading of the material on-site into an aggregate product with sensor-based on-line quality

assurance and a cement-paste concentrate that can be processed into a low-CO_2 input material for new cement.

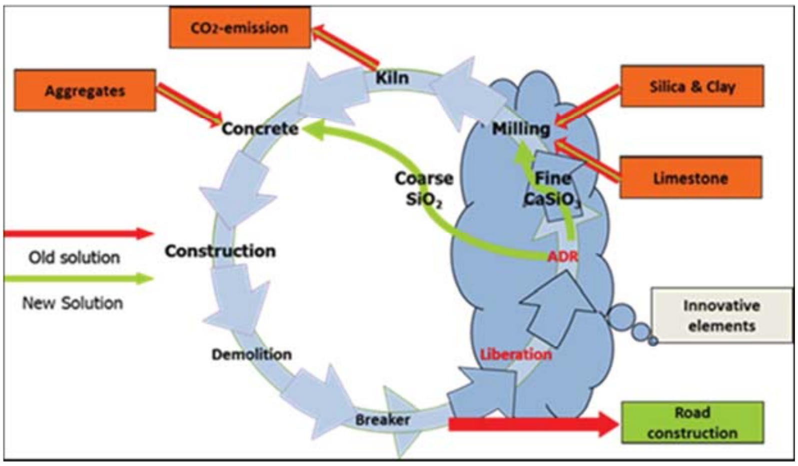

Fig. 1.C2CA in brief

In C2CA process, after crushing and sorting out big contaminants, liberation of the cement paste is promoted by several minutes of grinding in an autogenous mill while producing as little as possible new fine silica. A new low-cost classification technology, called Advanced Dry Recovery (ADR) is then applied to remove the fines and light contaminants with an adjustable cut-point of between 1 and 4 mm for mineral particles[3].The feasibility of this recycling process was examined in a demonstration project involving 20,000 tonnes of EOL concrete from two office towers in Groningen, the Netherlands and delivered very promising results[4]. Fine tuning of the C2CA process, requires a comprehensive understanding of the effects of various influencing parameters. In the C2CA process, the main factors which could affect the final properties of RA include the type of PC and the intensity of autogenous milling. In spite of the availability of considerable research aimed at a better understanding of the properties of RA and their influence on the performance of RAC, there are limited studies focusing on the effects of the involved recycling parameters in relation with the quality of final products [5-8].

The aim of current study is to enrich the knowledge with respect to the fine setting of C2CA process to deliver RA and RAC with high quality and salability potential. The present paper reports on the findings of an experimental study on the influence of "the type of PC and milling intensity" on the properties of RA.

Materials and Methods

1. Parent concrete

Three series of mostly utilized concrete in the Dutch market were chosen for casting as the Parent Concretes (PCs). To produce the specimens, ready mix concrete with real applications (see Table 3) and provided by Mebin (Heidelbegcement in the Netherlands), were used. The mix proportions for considered types of PC are presented in Table 4. PCs consists of CEM III B 42,5 N-LH and aggregates at three different grading with maximum sizes of 16 mm (for PC3) and 31.5 mm (for PC1 and PC2). PC1 and PC3 contain just NA, while PC2 consists of 10 wt.% of 16-32 mm RA in addition to NA due to the actual industrial usage of RA in the Netherlands. All specimens were cast in molds and compacted using vibrators. Samples were demolded after 24 h in a controlled laboratory environment and were cured in the standard condition according to the EN-12390-2. Fresh and hardened properties of the parent concretes were determined and the rest of the specimens were remained into the curing room for a duration of one year. For each type of PC about100 cubes of concrete (15×15×15cm) were casted to be used in RA and RAC production.

Table 3. Applications of the utilized parent concrete (PC) according to the descriptions in the EN 206-1.

Parent concrete code	Concrete Class	Place of utilization	Consistency Class	Environmental class
PC1	C28/35 D32	Wall	S3	XA2
PC2	C20/25 D32	Floor	S3	XC1
PC3	C20/25 D16	Wall	S3	XC3

Table 4. Mix proportions of Parent Concretes (PCs)

Component	PC1		PC2		PC3	
	Mass(kg)	Volume (dm^3)	Mass(kg)	Volume (dm^3)	Mass(kg)	Volume (dm^3)
CEM III B 42.5 N LH	337	115	260	89	324	111
water	173	173	180	180	187	187
NA 4-32 mm	1006	383	833	315	-	-
NA 4-16 mm	-	-	-	-	998	378
RA 4-32mm	-	-	200	79	-	-
NS 0-4mm	823	314	835	316	792	301
NS 0-1mm	-	-	16	6	23	9
Total weight of aggregates and sand (kg)	1829		1884		1813	
Air content(dm^3)	15		15		15	
w/c ratio	0.51		0.69		0.58	

*NA: Natural Aggregate, RA: Recycled Aggregate, NS: Natural Sand

2. Concrete recycling procedure

After almost one year curing, PCs were used as the input of the recycling process. Based on an experimental plan different types PC samples were recycled separately. For recycling, a lab-scale version of C2CA process was applied. Firstly, a laboratory jaw crusher with the opening of 20 mm was used to crush the parent concrete samples. In an industrial site, after crushing, EOL concrete is grinded in an autogenous mill to remove the fragile mortar from the surface of aggregates. During autogenous milling, the combination of shearing and compression forces, promotes selective attrition and delivers a better liberation. Thus, the milling intensity depends on the mentioned shear and compression forces. In this study, for grinding the crushed concrete and studying the influence of the milling intensity in a controlled way, a new experimental set-up was designed and constructed [9]. The schematic of this set-up with the name of Shear-Compression Machine (SCM) can be seen in Fig. 2. The SCM consists of a vertical cylinder for the application of the compression force. A ring-shaped container is placed under the vertical cylinder which is connected to an arm. An electrical engine connected to the arm is applied to move the container back and forth. The effective surface area of the container is 0.12 m^2, and for each test it can be filled out with approximately 22 kg of crushed PC. In this study, milling of materials in SCM was followed by a 16 mm screen and an ADR with the capacity of 60 tonnes per hour. Basically ADR is used to break the bonds that are formed by moisture and fine particles to separate them from coarse particles. The working principle of ADR is schematically shown in Fig. 3. In an industrial recycling site, ADR input materials usually contain certain amount of moisture. To simulate the same condition in the laboratory, the ADR input materials were moisturized artificially (water was added with the amounts of 5wt% of ADR input materials). In ADR after breaking up the material into a jet, the fine particles and contaminants such as wood, plastics and foams are separated from the coarse (In the real industrial conditions EOL concrete contains pollutants which should be separated). Fig. 4 shows different steps of the recycling process performed in this study.

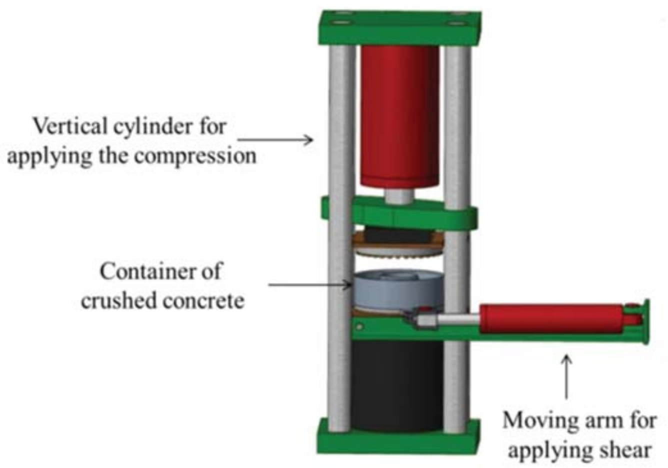

Fig. 2. The schematic of the Shear-Compression Machine (SCM).

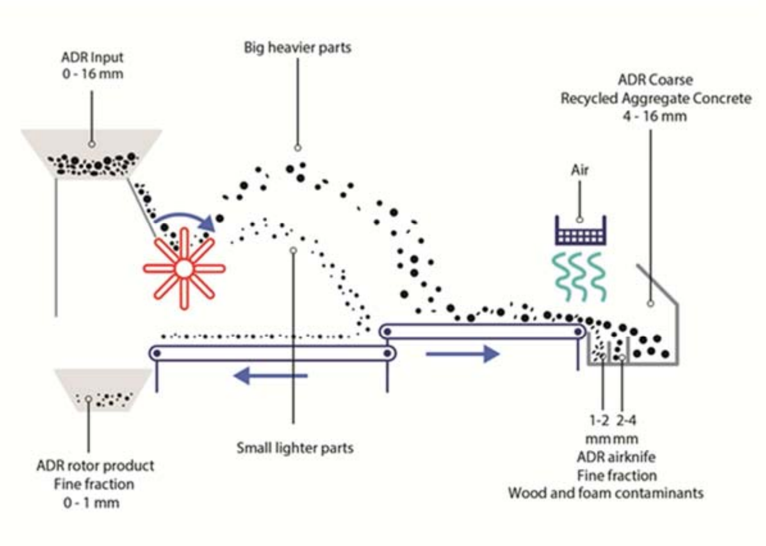

Fig. 3. Schematic of the ADR principle

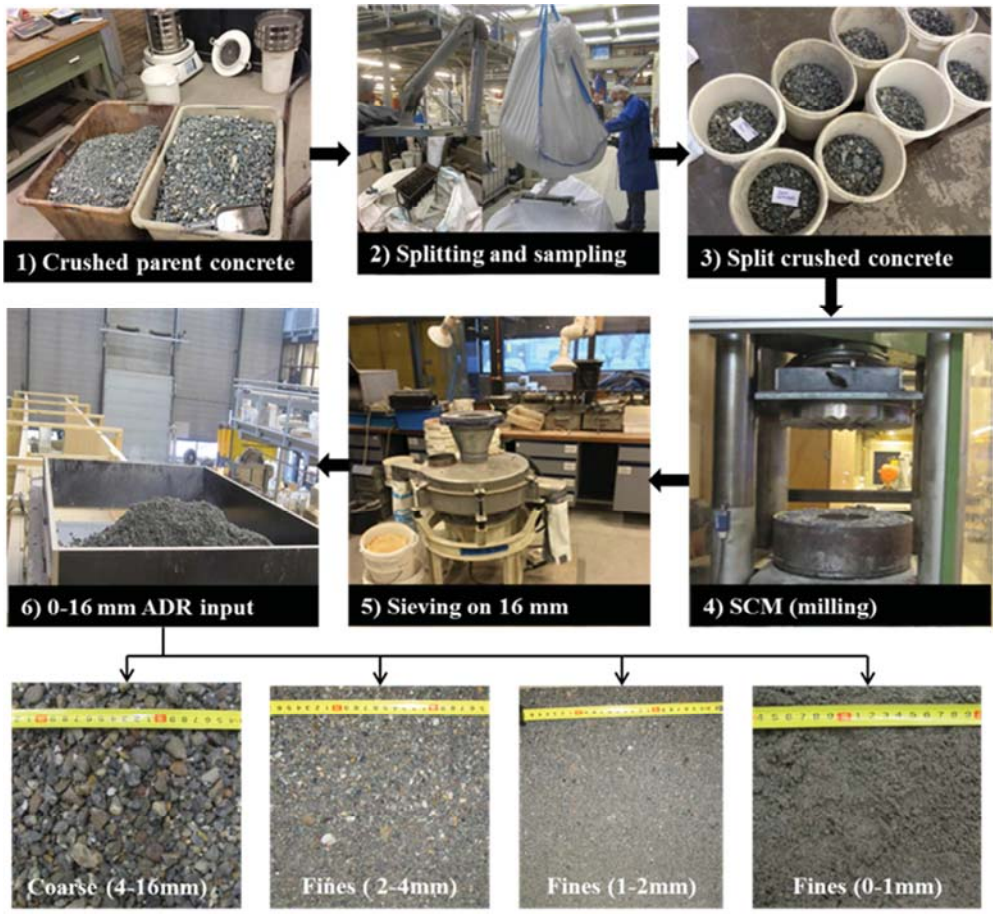

Fig. 4. Different steps of the performed recycling process and final produced recycled fractions

3. Experimental design

Experiments were designed to investigate the effects of the milling intensity, PCs types on the properties of the RA. Experimental runs with variations of the milling intensity and type of parent concrete resulted in the production of eight different types of RA (4-16 mm ADR coarse product). Table 5 provides detailed information about the considered experimental factors, their variables and coding of the produced RA.
Table **6** shows the list of tests and corresponding standards for determining the properties of RA, also fresh and hardened properties of concretes.

Table 5. Coding of the produced RA and their corresponding RAC

Parent concrete	SCM setting (degree of milling)			Coding of ADR input samples	Coding of corresponding produced RA
	Shear: Duration (min)	Compression: Force (KN)	Coding		
PC1	-	-	no milling	PC1-No Milling	◆ RA-PC1- No Milling
PC1	7.12	6.30	HS-LC	PC1-HS-LC	◆ RA-PC1-HS-LC
PC1	5.00	18.60	MS-MC	PC1-MS-MC	◆ RA-PC1- MS-MC

PC2	7.12	6.30	HS-LC	PC2-HS-LC	■ RA-PC2-HS-LC
PC2	5.00	18.60	MS-MC	PC2-MS-MC	■ RA-PC2-MS-MC
PC2	5.00	30.90	MS-HC	PC2-MS-HC	■ RA-PC2-MS-HC
PC3	7.12	6.30	HS-LC	PC3-HS-LC	▲ RA-PC3-HS-LC
PC3	5.00	18.60	MS-MC	PC3-MS-MC	▲ RA-PC3-MS-MC

Table 6.Test methods used for determining properties of RA and hardened RAC

Test	Standard
RA	
Density SSD [kg/m3]	EN 1097-6
Water Absorption [wt.%]	EN 1097-6
Resistance to crushing [wt. %]	PN-B-06714-40
Resistance to Freezing and Thawing[wt. %]	EN 1367-1

Results and Discussion

1. ADR performance

For each experimental run particle size distributions of ADR input and outputs were determined. Results of the particle size distribution analysis of different ADR coarse products showed negligible variations. Particle size distributions of ADR input and outputs and the recovery of each size fraction of all ADR products for sample PC3-MS-MC (as an example) are shown in Fig. 5 and Fig. 6 respectively.

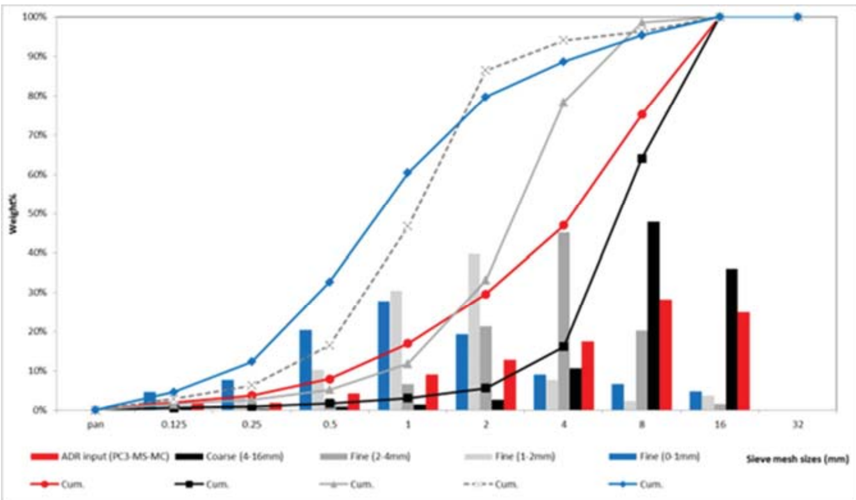

Fig. 5. Particle size distribution of ADR input and outputs. The lines show the cumulative curves whereas the bars indicate the absolute fraction weights.

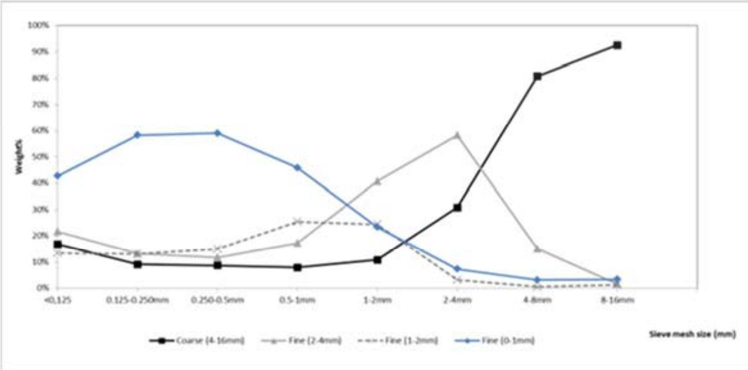

Fig. 6. The recovery percentage of each size fraction into the three products of ADR for sample PC3-MS-MC.

2. Properties of RA

Table 7 shows the physical and mechanical properties of produced RA. The guideline prepared by RILEM recommends recycled coarse aggregates for concrete production if their water absorption is between 3% and 10%[10]. According to recommendations of an international committee, coarse RA having water absorption capacity more than 7% is not desirable to be used in concrete [11]. In general, the values obtained for water absorption of RAs in this study corresponds well with the recommendations.

Table 7. Physical and mechanical properties of recycled aggregates

Properties	RA-PC1-No milling	RA-PC1-HS-LC	RA-PC1-MS-MC	RA-PC2-HS-LC	RA-PC2-MS-MC	RA-PC2-MS-HC	RA-PC3-HS-LC	RA-PC3-MS-MC
Moisture content [wt.%]	5.7	5.8	5.8	5.6	5.5	5.7	4.6	4.1
Density of grains[kg/m^3]	2626	2628	2629	2626	2629	2611	2626	2625
Density of grains dried in an oven[kg/m^3]	2265	2256	2249	2266	2290	2262	2330	2358
Density of grains saturated and surface-dried [kg/m^3]	2402	2397	2393	2403	2419	2395	2442	2460
Water absorption[wt.%]	6.06	6.26	6.41	6.04	5.62	5.89	4.82	4.30
Freezing-thawing weight loss (8-16mm) [wt.%]	1.06	0.75	0.91	2.14	3.53	2.32	1.3	1.22
Freezing-thawing weight loss (4-8mm) [wt.%]	1.86	1.69	1.96	5.40	6.01	7.43	2.54	2.35
Index of aggregate crushing for non-fractioned sample [wt.%]	14.42	14.6	14.43	13.74	13.79	13.16	13.21	13.98
Index of aggregate crushing for 4-8 mm fraction [wt.%]	13.49	13.84	13.38	14.02	13.32	13.31	12.74	13.04
Index of aggregate crushing for 8-16 mm fraction [wt.%]	15.65	15.88	15.86	13.31	14.37	12.95	13.93	13.65
Fines content [wt.%] (wet analysis)	0.63	0.23	0.37	0.29	0.31	0.43	0.40	0.34

This is well-known that the properties of RA vary proportionally with the amount of mortar present in RA. Research show that when the mortar content of RA increases, the density of RA drops and the water absorption raises[12]. In the present study, to investigate the importance level of two contributing parameters (milling intensity and type of PC) during recycling and their effects on the overall quality of RA, the variation in the water absorption of RA was utilised. Fig. 7 shows the effect of PC type and milling intensity on the water absorption of RA. In the figure type of PC is indicated with its 28 days achieved compressive strength. According to this figure the water absorption of RA generally decreases with reduction in parent concrete strength (Compare PC1 and PC2 which have the same maximum grain size but different strength). This trend is more obvious for RA coming from milling with higher intensity (MS-MC). This may be attributed to the fact that the stronger mortar present in the RA produced from parent concrete with higher strength, results in less mortar being removed during the primary crushing or by increasing the intensity of milling. Considering three different milling intensity (HS-LC, MS-MC and no milling) applied for PC1 which is the strongest utilised PC, it is obvious that changing the milling intensity has a slight effect on the water absorption of RA coming from PC1. On the other hand, water absorption of RA coming from weaker concretes is more influenced by changing the milling intensity.

Comparison between Fig. 7 and Fig. 8 shows an inverse relation between the water absorption and density of RA. In Fig. 8 it is clear that RA coming from PC1 with higher compressive strength, has lower density and density varies slightly by changing the milling intensity. This is another confirmation to the fact that milling intensity changes the mortar content for concretes with weaker strength more effectively. Results also showed that crushing of the PC to a maximum size close to that of their NA may result in some improvement in the density of RA (see PC3 with maximum NA grain size of 16 mm close to 20mm opening size of the crusher). The smaller difference between the size of the NA in PC and the space between the jaws of the crusher leads to the production of less amount of RA which contains more than one grain of NA adhered together and surrounding by mortar[8].

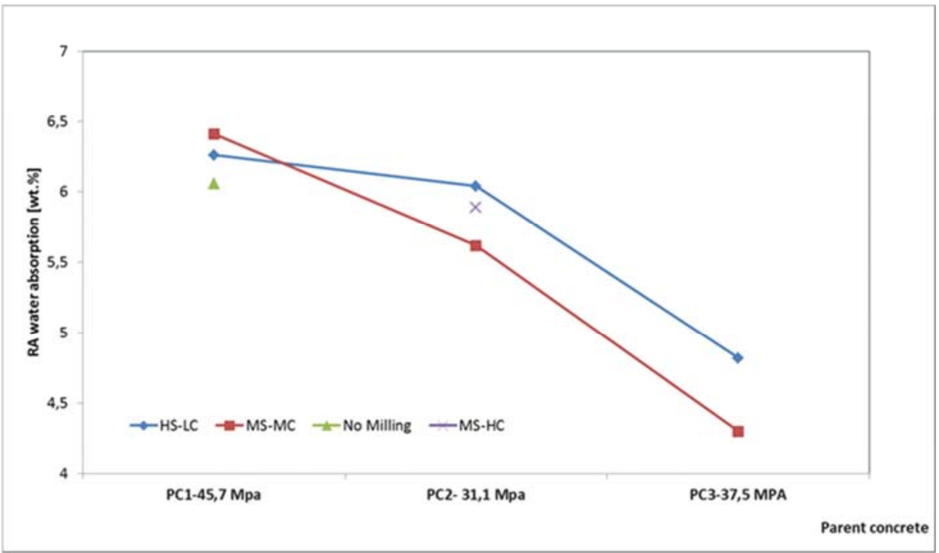

Fig. 7. The effect of the PC type and milling intensity on the water absorption of RA.

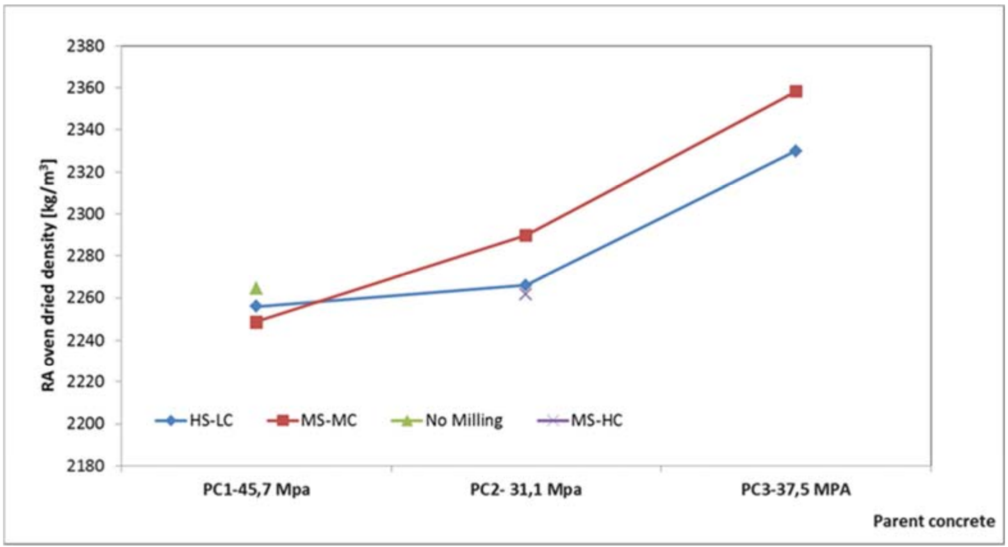

Fig. 8. The effect of the PC type and milling intensity on oven dried density of RA.

Crushing index is a parameter used to measure resistance of aggregate to fragmentation. Crushing index of various samples in Tbale 7 is another prove for existing a stronger mortar attached to RA coming from a stronger PC. Because of the adhered mortar, sometimes RA could result in higher crushing index.

For good quality coarse aggregates according to the requirements of PN-B-06714-40, the crushing index should be less than 16% which corresponds well with the results of this study (see Table 7). According to this table, the crushing index of RA coming from PC1 is just slightly higher than that coming from PC2 and PC3. Taking into account that RA coming from PC1 have relatively higher water absorption, one would expect also higher amount of crushing index due to the existence of more attached mortar. Thus, it can be concluded that the mortar attached to RA coming from PC1, is very strong and cannot be removed easily even after the crushing resistance test. According to the Polish national standard for the crushing resistance, all types of RA are ranked as “good”.

Considering Table 7 the influence of the type of PC can be observed also on the durability of RA. RA with the source of PC1 and PC3 presented really good freeze-thaw resistance (category F1 and F2 respectively) in contrast to RA coming from PC2 which showed weaker durability properties (Category F4). A comparison between compressive strength of PC and freeze-thaw resistance of RA, shows that an increase in the compressive strength of PC results in less weight loss of RA under freeze-thaw resistance cycles (see Fig. 9- red data points).

On the other hand, the correlation between freeze-thaw resistance of RA and freeze-thaw resistance of PC indicates a strong influence of the type of PC on the freeze-thaw resistivity of RA (see blue data points in Fig.9).

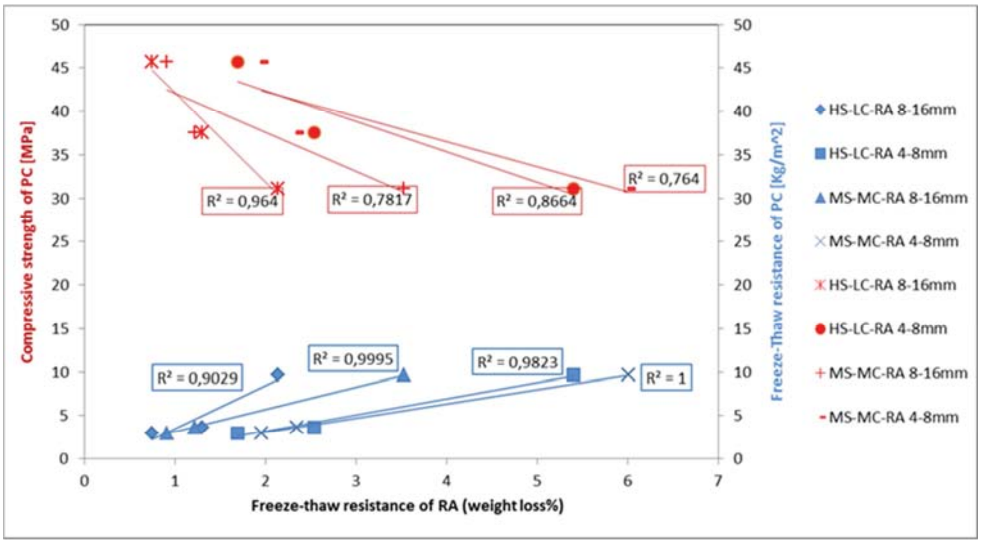

Fig. 9. Correlation between freeze-thaw resistance of RA and compressive strength of PC and correlation between freeze-thaw resistance of RA and freeze-thaw resistance of PC.

Conclusion

A new process for recycling of concrete to concrete (identified as the C2CA process) has been developed. This process aims for recycling of EOL concrete into high-grade aggregates and low-CO_2 raw material for the cement production. The industrial process applies selective demolition, autogenous milling and ADR as key technologies to deliver cleaner recycled aggregate. Among various liberation routes, autogenous milling, offers low complexity (mobile) and low-cost technology to remove the fragile mortar from the surface of aggregates. After milling, ADR efficiently separates the moist material into fine and coarse fractions. The overall conclusions based on the experimental results are as following:
Water absorption of produced RA is generally reduced with decreasing the strength of parent concrete. An inverse trend can be seen for the density of the recycled aggregates. Changing the milling intensity mostly influences the properties of RA coming from parent concrete with lower compressive strength. In fact, when parent concrete consists of stronger mortar, the properties of the produced recycled aggregate is less dependent on the milling intensity. According to the results, strong mortar on RA is not removed easily during both autogenous milling or crushing resistance test. According to the durability test results, the freeze and thaw resistance of parent concrete and recycled aggregate have a strong correlation. The relationship between the RA properties and considered recycling parameters, suggests that the type of the parent concrete is a prevailing parameter for the final properties of RA, in comparison with the milling intensity. Thus, among various milling intensities, and assuming the existence of mixed types of parent concrete in CDW, milling at medium shear and medium compression appears to improve the quality of RA with weaker attached mortar and consequently the overall quality of produced RA. In general, the results of the experiments on the produced recycled aggregates, indicate the qualification of all types of studied RA for RAC production.

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