EVALUATION OF THE CONCRETE PRISM AND THE ACCELERATED MORTAR BAR TESTS FOR ASSESSING THE POTENTIAL ALKALI-SILICA REACTIVITY OF RECYCLED CONCRETE AGGREGATES

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Abstract

The concrete prism test (CPT) and the accelerated mortar bar test (AMBT) are widely used tools for the assessment of alkali-silica reactivity of any given natural aggregates. This paper presents the evaluation of the above methods for evaluating the potential alkali-reactivity of recycled concrete aggregates (RCA). The testing was carried out on concrete prisms and mortar bars using respectively coarse RCA (CPT), as well as *crushed RCA* and *crusher's fines* (obtained from the primary crushing of the demolition concrete). The results showed that the behaviour in the CPT is very much related to the nature of the original virgin aggregates used in concrete manufacturing and the extent of ASR developed in the concrete prior to its demolition. In the case of the AMBT, the processing operations used to manufacture the fine size fractions required for mortar manufacturing has a critical impact on the proportion of residual mortar in the recycled concrete particles and, consequently, on the extent of mortar bar expansion. Consequently, a better correlation is obtained when CPT results are compared to that obtained when the AMBT is performed on *crushed RCA*.

Keywords: Recycled concrete aggregate, alkali-reactivity, concrete prism test, accelerated mortar bar test, residual mortar;

1 INTRODUCTION

As the most widely used material in infrastructure construction, concrete has significant environmental impacts. In fact, the worldwide cement production represents 6 to 7% of the annual carbon dioxide (CO_2) emission in the atmosphere. These emissions add to those issued by the aggregate mining and transportation processes. Concrete manufacturing and curing processes also use large amounts of water, a resource that is scarcely distributed and even in serious shortage in some parts of the world. This reality, associated with the fact that most of the concrete infrastructures built after the 1950-60's are reaching the end of their service life, while the pressure for sustainable development in concrete construction is increasing constantly, raised the interest in using recycled materials in the construction sector, including recycled concrete aggregate (RCA).

The long term performance of RCA still raises uncertainties, including their potential alkali-aggregate reactivity. Recent studies [1-2] demonstrated that the accelerated mortar bar test (AMBT) ASTM C1260 evaluates differently the ASR potential of RCA depending on the type of fine particles used for testing. The primary crushing process in industrial plants leads to the production of fine particles named *crusher's fines*. On the other hand, *crushed RCA* are produced in the laboratory for evaluating ASR potential of coarse RCA through accelerated mortar bar testing. The authors determined that the *crusher's fines* were generally under-evaluating ASR potential of the coarse RCA, so the *crushed RCA* has to be used in order to assess properly the ASR potential of the above material. However, the prior conclusion had been based on tests carried out on a limited number of RCA.

2 SCOPE OF WORK

While it was found in [1] that the residual mortar (RM) in the RCA particles had a critical effect on the expansion of the mortar specimens, it was therefore important to determine whether the RM had the same impact on the Concrete Prism Test (CPT), which is considered as the most reliable test for assessing ASR potential of concrete aggregates. In order to do so, a series of prisms (Series 1) were designed and manufactured in which the coarse RCA represented 25, 50 and 100% of the total coarse aggregate material in the concrete. A non-reactive limestone was used for the balance of the coarse aggregate in the concrete mixtures.

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In parallel, in order to verify the potential "tempering" effect of the RM on expansion due to ASR, another series of concrete specimens (Series 2) were manufactured without any RCA, i.e. by replacing the residual mortar by a non-reactive aggregate and the "reacted" aggregate material within the RCA by the same but "unreacted" original virgin aggregates (OVA).

The same approach was then used for two series of accelerated mortar bar tests, i.e. MB-1 - using 25, 50 and 100% of *crushed RCA*, and MB-2 - with no RCA but using "unreacted" OVA. The non-reactive CANMET sand was used to complete the aggregate fraction in both series of mortars, but also to represent the RM fraction in the series MB-2. A third series of mortar bars (MB-3) was also manufactured/tested as part of this study. These mortars were made with 25, 50 and 100% of *crusher's fines* (i.e. material obtained from the crushing of the concrete blocks to produce coarse RCA); similarly, to MB-1 series, the non-reactive CANMET sand was used to complete the aggregate fraction in the 25 and 50% mortar mixes. The results of MB-3 series will not be analysed in details here, as they were presented in another paper [1]; however, the 14-day results of MB-1 and MB-3 mortar series will be analysed against the expansion results of concrete prisms (Series 1) in order to evaluate the reliability of the AMBT for evaluating the potential alkali-reactivity of a variety of coarse RCA.

3 MATERIALS AND METHODS

3.1 Aggregate Materials and Block Specimens

RCA used in this study were obtained from the crushing of four sets of concrete blocks produced in the 1990s and that were subjected since then to natural environmental conditions on the CANMET outdoor exposure site in Ottawa (ON, Canada) [3,4]. Those blocks, 400 x 400 x 700 mm in size, were indeed made for evaluating ASR potential of reactive aggregates from different parts of Canada [3,4]. The age and the expansion reached by the blocks when they were crushed are presented in Table 1.

In order to manufacture coarse RCA, the blocks were initially broken into 100 mm maximum size pieces with a jackhammer, and then crushed to 0-20 mm particles with a swinghammer crusher. The material was then sieved to recover the following RCA fractions: -20+14 mm, -14+10 mm, -10+5 mm, -5 mm (*crusher's fines*). A representative sample of the coarse RCA fractions was then obtained by quartering (i.e. -20+5 mm) and then progressively ground with a small jaw crusher and a roller mill to produce the *crushed RCA* that was further used for manufacturing mortar bars.

The original virgin aggregates (OVA) used for block manufacturing were still available for further concrete prism testing, i.e. the Alberta gravel (AG), Bernier limestone (BL), Potsdam sandstone (PS) and Springhill greywacke (SL). In addition to these aggregates, a non-reactive natural sand (UL control) and a non-reactive pure limestone coarse aggregate (HP) were used for concrete prism testing, while another non-reactive sand (CANMET) was used for the mortar bar testing. The characteristics of all those aggregates are presented in Table 2.

3.2 Determination of the residual mortar content

Coarse RCA particles

As highlighted in a previous study carried out on RCA [2], the RM content of the coarse RCA strongly influences the performance of RAC. Its porous nature has a significant influence on the water available for the hydration of the new cement paste in RAC mixes. The method previously proposed by Abbas et al. [5], consisting of a combination of chemical and physical processes (i.e. five freeze-thaw cycles while being exposed to a sodium sulfate solution), allowed quantifying the proportions of the OVA and the RM in each of the various size fractions of the RCA.

For this study, the same method was selected, except that a roller mill was also used at the very end of the process to completely remove the RM that had been severely damaged by the freeze-thaw cycles in the sodium sulfate solution. The opening between each roller was equal or greater to the diameter of the particles used to avoid further crushing of the OVA. For each RCA, the RM content was calculated by mass difference for the various size fractions of RCA before and after completing RM disaggregation process described above. Table 3 presents the RM content (%) of each RCA used.

Fine RCA particles

As described in [6], thin sections were made from each of the five size fractions required for mortar bar testing, i.e. 4.75 – 2.36 mm, 2.36 – 1.18 mm, 1.18 – 0.63 mm, 0.63 – 0.30 mm, 0.30 – 0.15 mm. The proportions of RM and OVA were determined under the microscope by measuring the area covered by the RM and OVA in a large number of particles of each size fractions through image analysis. Table 4 presents the RM content (%) for each size fractions of *crushed RCA* used for mortar manufacturing.

3.3 Concrete prism testing (CPT)

The CPT was used for evaluating the potential alkali-reactivity of RCA, as well as to assess the reliability of the AMBT for the same purpose. The concrete was made according to CSA A23.2-14A, as follows and the mixtures are detailed in Table 5:

- Equal proportions of the various size fractions of RCA (5 – 10 mm, 10 – 14 mm, 14 – 20 mm);
- Coarse aggregates – to - fine aggregates ratio of 60/40, by weight;
- Cement dosage of 420 kg/m^3 (type GU cement with alkali content of 0.88 Na_2Oeq);
- Total alkali content in the concrete raised to 1.25% Na_2Oeq by the use of NaOH;
- Water-to-cement ratio between 0.42 and 0.45.

In order to evaluate the effect of the presence of the RM on the potential alkali-reactivity of the RCA, two (2) different series of concrete mixtures were manufactured in addition to the control series. Table 6 gives the details of the series used in this study, which are further explained below.

- Series 1: The coarse RCA is considered as 100% aggregate material, i.e. without considering the RM in the aggregate particles. The RCA and the non-reactive UL sand were used in a dry condition and the amount of water added to the mix was corrected to account for their absorption characteristics.
- Series 2: No RCA was used in this series of mixtures. The proportion of OVA in the RCA was replaced by the same original but "unreacted" virgin aggregates, while the RM was replaced by non-reactive HP coarse virgin aggregate. The coarse aggregates and the non reactive UL sand were used in a dry condition and the amount of water added to the mix was corrected to account for their absorption characteristics.
- A control series was made where the "unreacted" OVA and the non-reactive UL sand were used for concrete manufacturing. Both the "unreacted" OVA and the non-reactive sand were used in a dry condition and the amount of water added to the mix was corrected to account for their absorption characteristics.

In the case of Series 1, the RCA was used to represent 25, 50 and 100% of the coarse aggregate material. The non-reactive (HP) coarse aggregate was thus used to complement the RCA in this series of mixes (ex: 25% mix = 25% RCA with 75% HP).

In the case of Series 2 mixtures, which do not include any RCA, the proportions of "unreacted" reactive aggregates and HP coarse aggregates were calculated from the RM content measured on the various RCA (see Table 3), in order to match the same proportions of OVA and RM than those used in the Series 1 mixtures. For example, in the case of a RCA with an average content of 50% RM, the 25% RAC mixture of Series 2 will include 12.5% OVA and 87.5% HP. Table 7 gives the proportions of OVA and HP aggregate material in the various concrete mixtures of Series 2. One should note that the amount of aggregates used in one mixture is too small to generate enough volume variation regarding the difference between the RM and the OVA density.

3.4 Accelerated mortar bar testing (AMBT)

The mortar bars were made according to CSA A23.2-25A, as follows:

- Different proportions of the various fractions of aggregate materials (4.75 – 2.36 mm (10%), 2.36 – 1.18 mm (25%), 1.18 – 0.63 mm (25%), 0.63 – 0.30 mm (25%), 0.30 – 0.15 mm (15%));
- Total amount of 990 g of aggregates for 440 g of cement (type GU cement with alkali content of 0.88 Na_2Oeq);
- Use of Type GU cement with 0.90% Na_2Oeq for mortar manufacturing;
- Water-to-cement ratio of 0.50.

MB-1 is the exact same series as the CPT Series 1 described previously. The RCA was considered as 100% aggregate material, i.e. without any consideration to the RM content of the particles. The same three RCA contents were used, i.e. 25%, 50% and 100%, and the aggregate material was completed with the CANMET non-reactive sand. The RCA and the non-reactive sand were used in a dry condition and the amount of water added to the mix was corrected to account for their absorption characteristics.

On the other hand, no recycled aggregate material was used in the mortar series MB-2. Based on the RM content determined by image analysis for each particle size fraction of the *crushed RCA* [6] (Table 4), the proportion corresponding to the OVA in the RCA particles was replaced by unreacted OVA, while the CANMET non-reactive sand was used to complete the aggregate fraction and to substitute for the RM. Table 8 indicates the OVA and CANMET sand proportions used for the different series of mortar mixes.

As mentioned before, the MB-3 series is similar to the MB-1 series, but using 25, 50 and 100% *crusher's fines* (instead of using c*rushed RCA*).

4. RESULTS

4.1 CPT expansion

The expansion results obtained from the CPT series incorporating the four different reactive aggregates are presented in Figure 2.

The expansion of the BL Control set of prisms levelled off at about 0.15-0.16% after 26 weeks of testing, which indicates a high reactivity level according to CSA A23.2-27A Standard Practice [7]. The expansion of BL RAC increased with increasing proportions of RCA in the mix (i.e. from 25 to 100% of RCA – Series 1; Figure 2A), reaching a maximum expansion of about 0.04% for the mixture incorporating 100% RCA. For the Series 2, increasing the amount of "unreacted" OVA in the mixtures also resulted in increased expansions in the specimens, (i.e. see 25 to 100%, Series 2, Figure 2A). Interestingly, similar but somewhat limited expansions were obtained for the two series of concrete prisms that used similar proportions of the BL aggregates in the mixtures, either as unreacted OVA (Series 2) or as reacted OVA contained in the RCA (Series 1).

In the case of the SL aggregate, an expansion of about 0.32% was obtained at 52 weeks for the Control set of prisms, which classifies the aggregate as extremely reactive according to CSA A23.2-27A Standard Practice [7]. Increasing expansions were obtained with increasing amounts of RCA particles (i.e. from 25 to 100% of RCA – Series 1; Figure 2B), with a maximum one-year expansion of about 0.125% reached with the 100% RCA mixture. When the "unreacted" SL aggregates particles were used, increasing expansions were also obtained with increasing reactive material in the mix (i.e. from 25 to 100%, Series 2, Figure 2B). It is interesting to note that the test prisms incorporating "unreacted" OVA expanded by about 70% more than those incorporating similar proportions of "reacted" OVA particles (i.e. compare, for example, SL Series 1 100% to SL Series 2 100%). Also, the expansion curves of the Series 2 prisms practically levelled off after 26 weeks of testing, while those of the Series 1 prisms still showed trends for increasing expansion at the end of the 52-week testing period.

Although showing lower expansion values, the behaviour of the various series of concrete prisms incorporating the PS aggregate was found to be very similar to that of the concrete prisms made with the SL aggregate and described in the previous paragraph (Figures 2C), with the exception of the PS Series 1 25% prisms that showed a behaviour that remains unexplained at this stage. According to the expansion results obtained for the PS Control set of prisms, the PS aggregate can be classified as moderately reactive according to CSA A23.2-27A Standard Practice [7].

Finally, with an expansion of about 0.14% at one year (Control set), the aggregate AG is classified as highly reactive according to CSA A23.2-27A Standard Practice [7]. This aggregate, however, induced a somewhat "inconsistent" behaviour. On one hand, and similarly to the other aggregates, increasing expansions were obtained with increasing amounts of RCA particles (i.e. from 25 to 100% of RCA – Series 1; Figure 2D). Interestingly, the expansion rate of the set of control prisms largely slowed down after 26 weeks of testing, while the prisms incorporating 100% RCA showed a steadily increasing rate of expansion over the one-year testing period and expanded by about 30% more than the former at 52 weeks. On the other hand, only slight expansions gains were observed when the "unreacted" AG aggregates particles were used in the mixtures (from 0.06% to 0.08% between Series 2 25% and 100%; Figure 2D); also, and contrary to the other aggregates, lower expansions were observed when similar proportions of the OVA are present in the mixtures as "unreacted" particles compared to when present as part of RCA particles (i.e. compare 50 and 100% mixes, Series 2 vs Series 1).

4.2 AMBT expansion

All the expansion results obtained from the MB-1 and MB-2 series are presented in Figure 3. The graphs show the expansion reached over 14 days depending on the replacement level of the different components of the mixtures.

Very different behaviors were observed for the two series of BL mortar bars. On one hand, increasing expansion was obtained with increasing proportions of "unreacted" OVA in the mix (MB-2 series), with expansions ranging from 0.08 (25%) to 0.16% (100%) at 14 days. On the other hand, very similar expansions were obtained for all mortar mixtures incorporating various proportions of RCA (MB-1 series), i.e. ranging from 0.085% (25% RCA) to 0.095% (50% RCA) (Figure 3A).

The mortar bar series incorporating the SL and AG reactive particles showed similar and steadily increasing expansive behaviors over the 14-day testing period. For both aggregates, the 50% and 100% MB-1 and MB-2 mortar mixtures, despite differents expansion rates over the 14-day period, finally expanded by about the same amount, i.e. 0.28 to 0.30%, after 14 days of testing. The 25% MB-1 and MB-2 mortar mixtures expanded slightly less than the 50% and 100% mixes, but by the same amount, i.e. about 0.20%, after 14 days of testing.

Finally, increasing expansions were observed with increasing amounts of PS aggregate material in the mortar mixtures. The 50% and 100% MB-1 mortars gave the highest expansions, with 14-day expansions ranging between 0.06 and 0.08%. However, the 14-day expansions were largely lower than the 0.15% expansion limit generally used to identify reactive aggregates in the AMBT.

5. DISCUSSION

5.1 Alkali-reactivity assessment standards

Concrete prism test (CPT)

The CPT carried out in this study largely showed increasing expansion with increasing proportions of reactive materials in the mixtures. No pessimum effect was thus obtained for RAC incorporating the four different rock types selected, and for RCA contents ranging from 25 to 100%.

Lower concrete prism expansions were generally obtained when a given amount of OVA is found as part of recycled aggregate particles (i.e. Series 1) compared to when it is used as separate ingredient in the concrete (i.e. Series 2). This was expected since the reactive aggregates in Series 2 are unreacted and totally exposed to the concrete pore solution (instead of being partly surrounded by residual mortar). The difference was not found to be that significant for the moderately reactive aggregates PS and BL, while it was much more important in the case of the highly reactive aggregate SL. The concrete blocks incorporating the SL aggregate had shown large expansion (0.563%) over 16 years of outdoor exposure, which likely used a fair amount of reactive silica within the OVA SL particles. The use of "unreacted" SL particles in Series 2 concrete prisms was thus prone to generate higher expansions compared to Series 1 concrete mixtures.

An opposite behavior than the one described above was obtained in the case of the AG aggregate, where larger expansions were obtained in the case of concrete mixtures incorporating RCA particles (series 1). This situation is possibly related to the nature of the AG aggregate, a river gravel. In fact, the RM content in Series 2 concrete prisms was substituted by a non-reactive aggregate (HP), while the same original ("unreacted") virgin aggregate (OVA) was used as the reactive material in that series of concrete mixtures. Virgin gravel aggregate particles generally have smooth and somewhat "stabilized" external surface area with minimal visible micro cracking because of lower processing operations. Therefore, these aggregate particles may be relatively less reactive than the RCA particles that were manufactured by crushing blocks incorporating these OVA. The RCA production from the AG blocks indeed generated RCA particles with by far the lowest RM content of all RCA (Table 3), as well as several fresh fractured surfaces and microcracks that possibly lead to higher ASR reactivity as the pore solution has a greater ability to reach the AG aggregate's reactive phases.

Accelerated mortar bar test (AMBT)

The AMBT conducted in this study showed that, generally, increasing expansion is reached with increasing proportions of reactive materials in the different mixtures. Although a few samples incorporating lower proportions of reactive material actually reached higher expansion levels than samples with a higher amount of reactive material, the difference between their final expansion levels was so small that it is impossible to conclude in favour of a pessimum effect.

In most cases, only small differences were obtained between the 14-day expansions of mortar bars incorporating the same proportion of reactive aggregate material, either as "unreacted" material (i.e. MB-2 series) or as part of RCA particles (i.e. MB-1 series). This suggests that the crushing process used for generating the various aggregate size fractions required for mortar manufacturing is generating enough fresh surfaces, even in the case of "reacted" OVA incorporated in RCA particles, thus producing similar expansions as that generated when a similar proportion of "unreacted OVA particles" are used for testing. This also suggests that there was still sufficient reactive silica available in the OVA incorporated in the RCA to generate excessive expansion in the AMBT, even after the blocks from which the RCA were produced had been subjected to 14-16 years of outdoor exposure testing. The only exception to the above findings were obtained for mortar mixtures BL-100% and PS-100%. The latter showed respectively 0.068% and -0.044% differences in expansion between MB-2 and MB-1 series. The exact reason for this difference in behaviour is still unknown at this stage.

Regarding the PS reactive material, the difference between the various sets of mortar bars was somewhat limited, i.e. ranging between 0.04 and 0.08%. In fact, the accelerated mortar bar test was found unreliable for evaluating the potential alkali reactivity of siliceous sandstone such as the Potsdam aggregate. It was indeed shown that the crushing process involved in the production of PS OVA fine particles eliminates the reactive siliceous phase contained in the OVA [7,8].

Reliability of the AMBT for RCA

As described in [1,2], important differences in expansive behaviors were observed between the bars made with the *crusher's fines* and those made with the *crushed RCA*. Petrographic analysis indicated that the lower expansions observed for mortar bars made with the *crusher's fines* was due to their higher RM content [6], making the *crushed RCA* a more reliable material for properly assessing the ASR potential of coarse RCA material. The above findings were however based on one type of RCA material only.

Figure 1 compares the results obtained for mortar series MB-1 (*crushed RCA*) and MB-3 (*crusher's fines*) when correlated to CPT (Series 1), for the different mix designs incorporating 25 to 100% RCA. This graph highlights four different zones, i.e. those where the CPT (0.040% expansion limit) and the AMBT (0.150% expansion limit) agree on the potential reactivity of the tested aggregates (green and red), and those where the two tests disagree (grey zone). It appears that 10 out of 12 (83%) MB-1 samples reached expansion that allowed both tests, AMBT and CPT, to classify the samples as reactive or not. On the other hand, 9 out of 12 (75%) MB-3 samples were classified similarly by both tests. Interestingly, if the limit for the AMBT was lowered to 0.10% at 14 days, then 9 out of 12 (75%) MB-1 samples but 11 out of 12 (92%) MB-3 samples would be classified similarly by both tests. The comparison showed in Figure 1 suggests that the AMBT has the potential of reliably evaluating the potential alkali reactivity of RCA; however, despite some relatively close statistics and considering the strong effect of the RM particles in the test, using *crushed RCA* as the fine particles for the AMBT test remains the preferred approach to generate more accurate results.

6. CONCLUSION

The different concrete prisms and mortar bar series manufactured for this study, associated with results coming from past investigations [1,2], provided useful information regarding the evaluation of potential alkali reactivity and of the ASR expansion mechanisms of concrete incorporating RCA.

The results obtained in this study suggests that the extent of concrete prism expansions obtained for concrete made with RCA will vary from one type of OVA to another, as well as a function of the history/age (e.g. extent of ASR expansion reached) of the demolition concrete. In the case of the AMBT, the extent of expansion will also be a function of the reactivity level of the OVA; however, the crushing operations used to manufacture the aggregate particle size fractions used for mortar manufacturing seem, in many cases, to "reactivate" enough reactive surfaces to produce fairly large expansions in the test.

Nevertheless, for the sets of materials testing in this study, the CPT performed on coarse RCA and the AMBT performed on *crushed RCA* generally showed similar assessments of the potential alkali-reactivity of the aggregate tested. Petrographic examination of mortar bars and concrete prisms is currently in progress to further analyse the signs of deleterious expansion in the test specimens, thus allowing a better understanding of the mechanisms involved.

7. REFERENCES

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TABLE 1: Age and expansion reached by the various sets of exposure blocks when they were crushed to produce RCA.

Block Identification	Year of manufacturing	Age of blocks at the time of crushing (years)	Range of expansion of the blocks (%)[1]	Average expansion (%)
BL	1995	14	0.142 - 0.183	0.162
PS	1995	14	0.066 - 0.145	0.092
SL	1993	16	0.423 - 0.537	0.480
AG	1995	14	0.210 - 0.305	0.263

[1] Each set used for manufacturing RCA was composed of 4 or 5 blocks, 400 x 400 x 700 mm in size.

TABLE 2: Natural aggregates used in this study.

Aggregate		**Origin**	**Type**	**Type of rock**	**Density g/cm³**	**Absorption (%)**	**Reactivity level [3,4]**
Aggregates used to make the original CANMET blocks (OVA)	Bernier (BL)	St-Jean-sur-le-Richelieu (Québec)	Quarry	Siliceous and argillaceous limestone	2.70	0.51	Moderate
	Potsdam (PS)	Montréal (Québec)	Quarry	Siliceous sandstone (orthoquartzite)	2.57	1.15	Moderate
	Springhill (SL)	Fredericton (New-Brunswick)	Quarry	Greywacke	2.70	0.50	Very high
	Alberta (AG)	Calgary (Alberta)	Gravel pit	Limestone, Sandstone, Quartzite and fine-grained volcanic rock	2.61	0.89	Moderate
Other aggregates used to make recycled aggregate concretes	High purity (HP)	Western Newfoundland	Quarry	Limestone	2.67	0.40	Non-reactive
	Sand (CANMET control)	Cantley (Québec)	Natural sand	Derived from granite	2.70	0.81	Non-reactive
	Sand (Laval University)	Québec City (Québec)	Natural Sand	Derived from granite	2.70	0.56	Non-reactive

TABLE 3: Residual mortar content for each size fractions of the coarse RCA used in this study.

Coarse RCA	Residual mortar content (%) for the different aggregate size fractions (mm)			
	-20+ 14	-14 + 10	-10+ 5	Avg.
BL	35.6	33.7	46.9	40.7
PS	38.6	34.4	50.9	43.7
SL	32.5	34.8	45.3	39.5
AG	22.3	19.3	23.5	22.1

TABLE 4: Residual mortar content of each size fractions of the *crushed RCA* used in this study.

	Residual mortar content (%) for each size fraction use for the AMBT (mm)					Average[1]
	4.75 – 2.38	2.38 – 1.18	1.18 – 0.63	0.63 – 0.30	0.30 – 0.15	
BL	33.9	36.8	40.4	31.7	36.6	36.1
PS	74.1	68.6	60.7	23.6	17.4	48.2
SL	24.7	28.9	29.9	33.0	45.1	32.2
AG	42.0	44.9	50.1	52.1	58.0	49.7

[1]The average was calculated taking into account the proportion of each size fraction needed in the mortar mixtures.

TABLE 5: Testing matrix.

	RCA content in the mix [1]			
	BL	SG	PS	AG
Series 1	25, 50, 100%	25, 50, 100%	25, 50, 100%	25, 50, 100%
Series 2	25, 50, 100%	25, 50, 100%	25, 50, 100%	25, 50, 100%
MB -1[2]	25, 50, 100%	25, 50, 100%	25, 50, 100%	25, 50, 100%
MB-2	25, 50, 100%	25, 50, 100%	25, 50, 100%	25, 50, 100%

[1]As indicated in Table 5, concrete mixtures of Series 2 do not incorporate any recycled aggregate material; however, the proportions of coarse aggregates were calculated to simulate the presence of RM in the mixture.
[2]AMBT series produced in [1]

TABLE 6: Concrete prism test series and their different properties.

Properties of the mixture	Series 1	Series 2	Control
Residual mortar *not taken* into account.	√		
Residual mortar *taken* into account		√	
RCA particles used	yes	no	no

TABLE 7: Proportions of Series 2 concrete mixtures.

RCA	Proportions of "unreacted" OVA and HP in the different mixtures of series 2 (OVA / HP) (%)		
	25%	50%	100%
BL	10.9 / 89.1	20.9 / 79.1	40.7 / 59.3
PS	11.7 / 88.3	22.4 / 77.6	43.7 / 56.3
SL	10.6 / 89.4	20.3 / 79.7	39.5 / 60.5
AG	6.3 / 93.7	11.5 / 88.5	22.1 / 77.9

TABLE 8: Proportions of the different mortar mixtures of the MB-2 series.

RCA	Proportions of "unreacted" OVA and of UL sand in the different mixtures of MB-2 (OVA/CANMET) (%)		
	25%	50%	100%
BL	12.2 / 87.8	23.4 / 76.6	45.8 / 54.2
PS	14.6 / 85.4	28.1 / 71.9	55.3 / 44.7
SL	11.1 / 88.9	21.2 / 78.8	41.4 / 58.6
AG	15.4 / 84.6	29.8 / 70.2	58.6 / 41.4

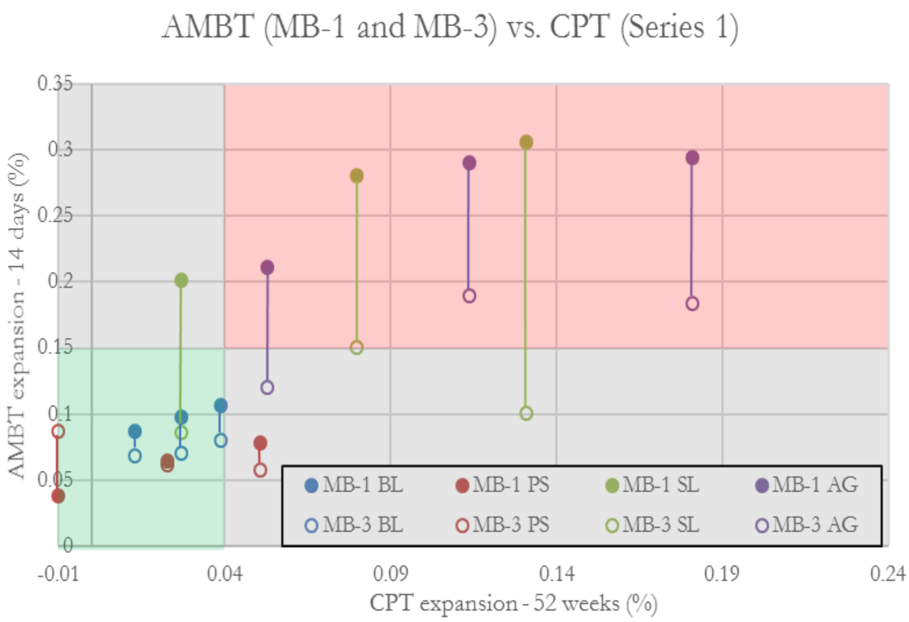

FIGURE 1: AMBT expansion (14 days) versus CPT expansion (52 weeks).

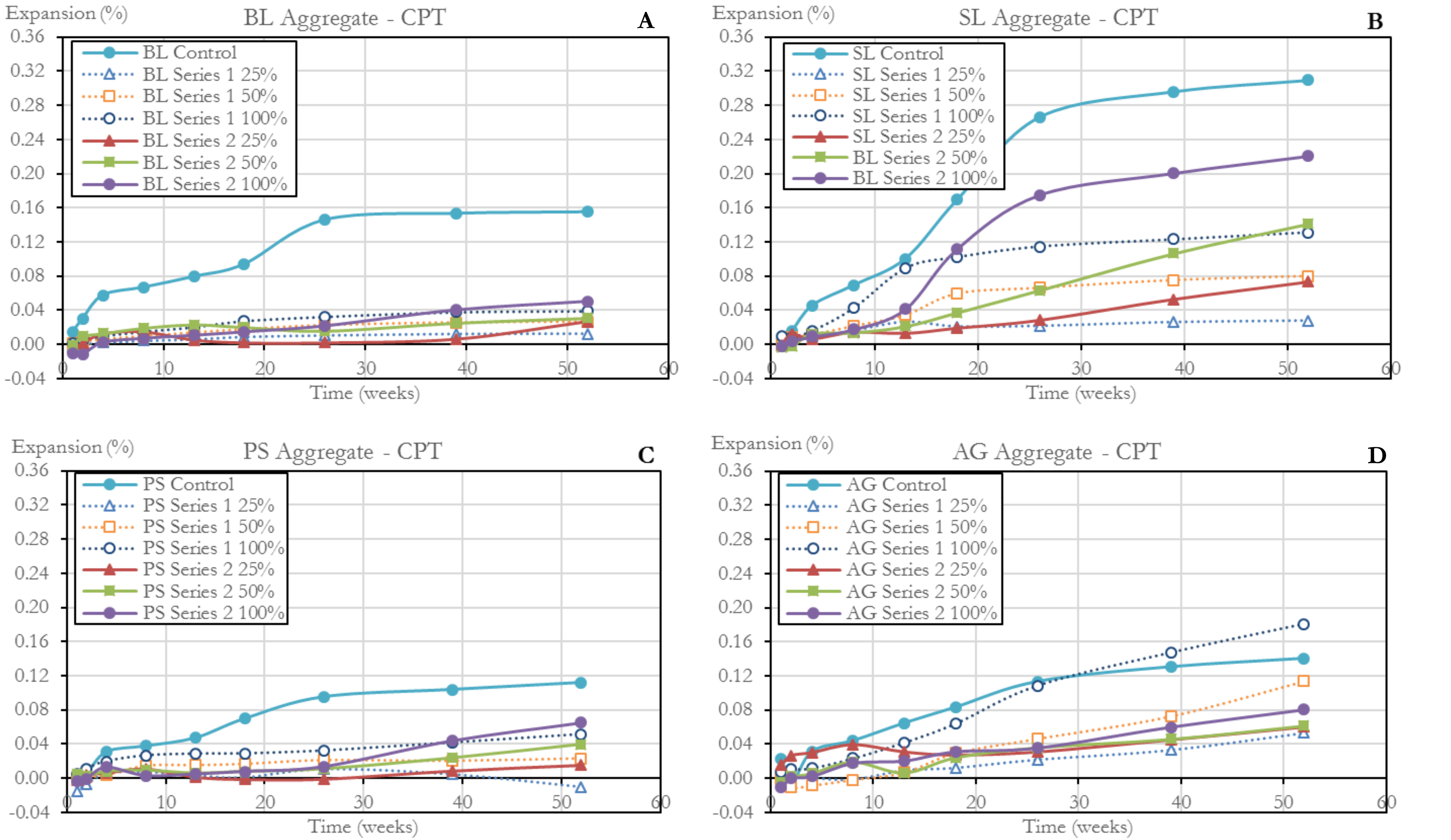

FIGURE 2: Concrete prism test expansion over 52 weeks (Series 1 and Series 2); 2A: BL aggregate - CPT Series 1 and Series 2; 2B: SL aggregate - CPT Series 1 and Series 2; 2C: PS aggregate - CPT Series 1 and Series 2; 2D: AG aggregate - CPT Series 1 and Series 2.

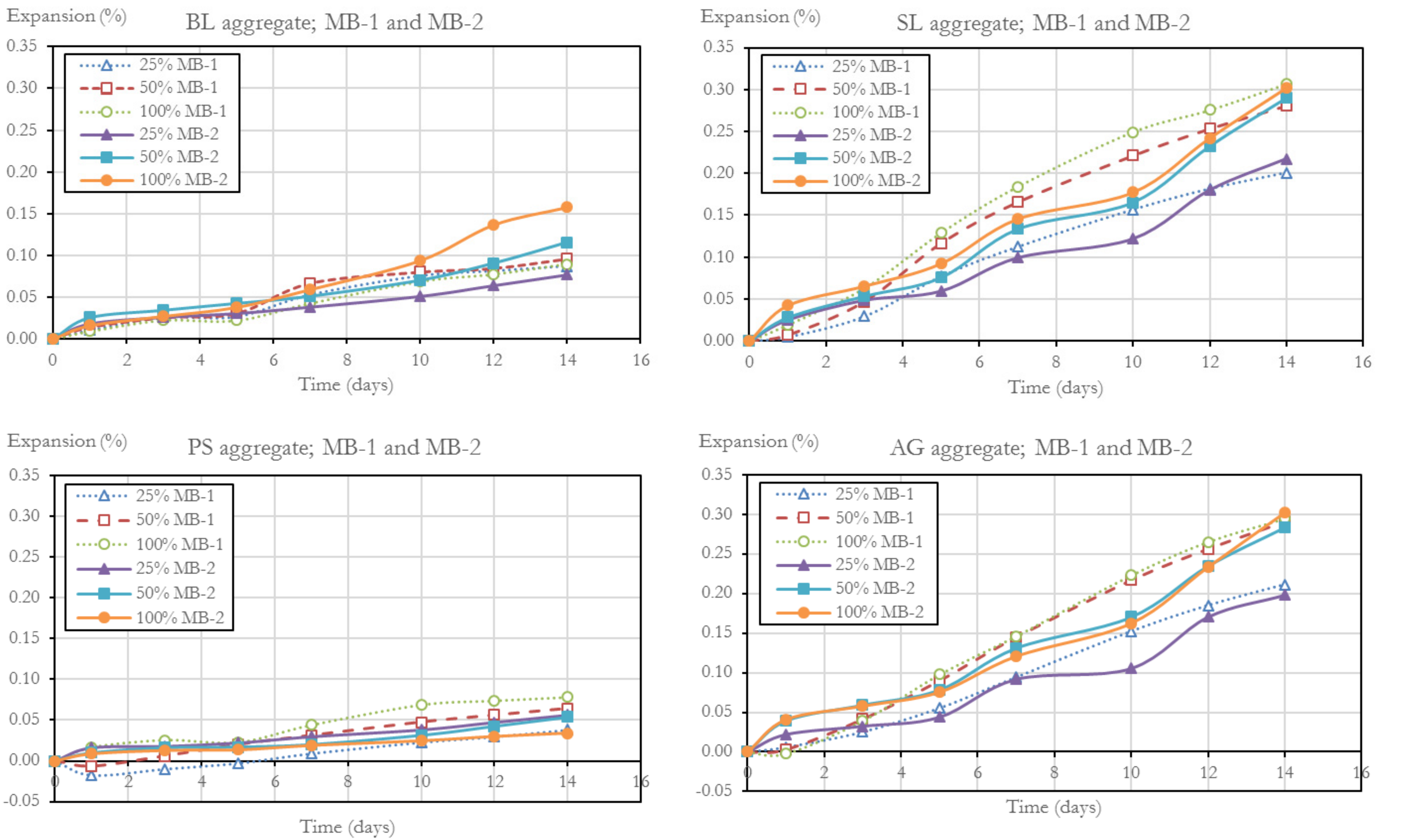

FIGURE 3: Accelerated mortar bar test over 14 days (MB-1 and MB-2) 3A: BL aggregate – MB-1 and MB-2 ; 3B: SL aggregate – MB-1 and MB-2; 3C: SL aggregate – MB-1 and MB-2; 3D: AG aggregate – MB-1 and MB-2.