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Treatment of Recycled Concrete Aggregates by Si-Based Polymers

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***Abstract*—**The recycling of concrete, bricks and masonry rubble as concrete aggregates is an important way to contribute to a sustainable material flow. However, there are still various uncertainties limiting the widespread use of Recycled Concrete Aggregates (RCA). The fluctuations in the composition of grade recycled aggregates and their influence on the properties of fresh and hardened concrete are of particular concern regarding the use of RCA. Most of problems occurring while using recycled concrete aggregates as aggregates are due to higher porosity and hence higher water absorption, lower mechanical strengths, residual impurities on the surface of the RCA forming weaker bond between cement paste and aggregate. So, the reuse of RCA is still limited. Efficient polymer based treatment is proposed in order to reuse RCA easier. The silicon-based polymer treatments of RCA were carried out and were compared. This kind of treatment can improve the properties of RCA such as the rate of water absorption on treated RCA is significantly reduced.

***Keywords*—**Recycled concrete aggregates, water absorption, silicon-based agent and polymer.

I. Introduction

INCREASING problems with waste management and reducing natural resources of aggregates (sand and gravels) support the recycling of the accumulating waste materials. If the view of a sustainable material flow is to be realized, the amount of recycled waste has to be increased. The building industry in particular is a major consumer of materials and a major producer of waste at the same time. One possible way is to recycle and reuse waste from construction and demolition as concrete aggregates. Unfortunately, the composition of these aggregates can vary substantially and consequently their properties have a significant influence on the properties of the concrete [1-5].

The reuse of RCA in concrete as usual aggregates will contribute to valorize these wastes within the framework of the sustainable development. However, its application in construction field is still limited. In general, the properties of concrete made with recycled concrete aggregates, were assessed and are inferior to these natural aggregate concrete.

The physical properties of recycled aggregates depend on both adhered mortar quality and the amount of adhered mortar.

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The adhered mortar is a porous material; its porosity depends upon the w/c ratio of the recycled concrete employed [6-7]. The crushing procedure and the dimension of the recycled aggregate have an influence on the amount of adhered mortar [8-12].

The density and absorption capacity of recycled aggregates are affected by adhered mortar. The absorption capacity is one of the most significant properties which distinguish recycled aggregates from natural aggregates, and it can have an influence both on fresh and hardened concrete properties. In addition, the presence of cracks and the porous nature of the old cement mortar affect the bond between the RCA and cement paste when used in new concrete.

At the present time, two improvement ways, available in literature, are used to offset the loss of recycled concrete aggregates properties. The first way, of improving the qualities of concrete based on recycled aggregates, is to modify the mixing processes. And the second one is to change the mix design process and adapt to the new mix concrete containing recycled aggregates. The modification of the mixing process (via two or three step mixing) allows improving the behavior of concrete, according to Otsuki et al. [13] and confirmed by Kong et al. studies [14]. As for the mix design, most of methods already used are to restrict substitution of recycled aggregates, to maintain use fine natural mineral additives used as partial replacement of cement and/or adding reducing agents to water [15-16].

In this context, the investigation, presented here, deals with the study on the influence of different polymer based treatments on RCA (4-20mm), already used in the protection of structures (grout, render...) This paper reports an experimental study to improve the properties of recycled concrete aggregates (RCA) by their polymer based treatment. The effects of recycled concrete aggregates treated on the water absorption, the microstructure and toughness resistance of the recycled concrete aggregates were evaluated.

The aim is to determine the best conditions for an efficient and sustainable polymer impregnation (PI) improving physical and mechanical RCA properties which should become closer to natural aggregates. In addition, the mode of treatment should be compatible with building yard practice.

II. Materials

A. Aggregates as Substrates

Natural and recycled aggregates were used as the coarse aggregates. In this study, crushed granite was used as the natural aggregates. Natural crushed aggregates are limestone type (also called Boulonnais). The density of limestone is 2.7

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g/cm3. Two types of recycled concrete aggregates (RCA) were used. Moze recycled concrete aggregates (Moze) were crushed and obtained from the demolishing of reinforced concrete buildings in France. Conventional concrete were made to overcome the problem of heterogeneity due to the complexity of the mixtures of recycled aggregates. The e/c ratio is 0.49. The density is 2.5 g/cm3. The advantage of this choice is to control all stages of the mix design of concrete from the curing conditions to storage, which could be controlled. After 90 days of cure, the concrete was crushed in distinct granular fractions to “LR Autun” center (France). These concrete homemade crushed form recycled aggregate as "conventional recycled aggregates" (also called BO) allow easing the reproducibility of the tests and having a database of conventional recycled aggregates.

B. Set of Polymers based Treatments (see Table I)

Five commercial silicon based emulsions were screening. These different emulsions are composed of alkylalkoxysilanes (also called silane), polydiorganosiloxanes (also called siloxane) or both of them. These are silicon based polymers. These compounds are suitable water repellent polymers. These emulsions were supplied by Wacker and Dow Corning companies respectively. A soluble sodium silicate, which is industrial grade product, was also used without further purification (see Fig. 1).

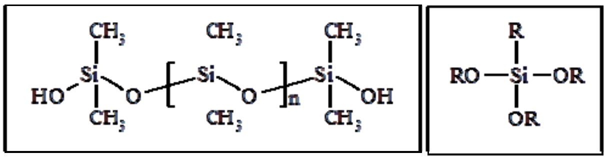

Fig. 1 Polydimethylsiloxane and alkyltrialkoxysilane

TABLE I
SET OF POLYMER BASED TREATMENTS

Treatment acronyms	Names of product	Polymer compositions	Concentration gradient
P0	sodium silicate solution	sodium silicate	7 to 30%
P1	BS 1 Wacker emulsion	siloxane/silane	5 to 50%
P2	IE Dow Corning emulsion	silane	5 to 50%
P3	BS 3 Wacker emulsion	siloxane/silane	5 to 50%
P4	BS 4 Wacker emulsion	siloxane/silane	5 to 50%
P5	BS 5 Wacker emulsion	siloxane/silane	5 to 50%

III. METHODOLOGY

A. Polymer Treatment

Different polymer solutions were prepared with different concentrations. Then, RCA were soaked in these polymer solutions which correspond to polymer treatments. The polymer treatments were conducted under a controlled laboratory environment. The optimal concentration and combination of polymer based treatment required to improve the recycled aggregates were determined.

B. Water Absorption Measurement (EN NF 1097-6) and Abrasion Resistance by Los Angeles Mass Loss Test (EN NF 1097-2).

The water absorption, porosity and toughness resistance (Los Angeles trials) were carried out on untreated recycled concrete aggregates (Reference) and RCA treated by polymer impregnation (PI-RCA).

IV. RESULTS

A. Water Absorption Capacity on Natural and Recycled Aggregates without any Treatment

Water absorption of natural and recycled aggregates was assessed in water by total immersion for 48 hours. Capillary water absorption coefficients were determined on different granular fraction before any treatment and presented in Fig. 2.

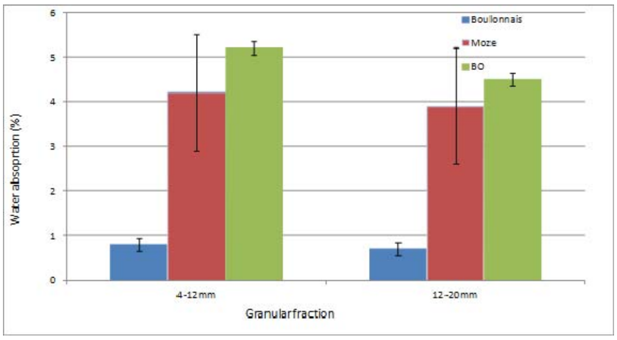

Fig. 2 Water absorption coefficient vs granular fraction on natural aggregates, RCA and treated RCA at 48h

Natural aggregates (Boulonnais) do not absorb a lot of water. The water coefficient of natural aggregates is less than 1%. In contrast, the water absorption coefficient of recycled is between 4 to 5%. Recycled concrete aggregates (Moze and BO) absorb up more than natural aggregates and whatever granular fraction (around 400 times higher than natural aggregates). The presence of primary adhered mortar of recycled concrete aggregates) is the main responsible for the increase of water absorption. The water saturation maxima of natural aggregates were achieved for 24h as described in EN NF 1097-1 while the water saturation maxima of recycled concrete aggregates was obtained over 24 h of immersion. The water saturation maxima of RCA are achieved for 48h.

B. Water Absorption Capacity on Treated Recycled Concrete Aggregates by Polymer Impregnation (PI-RCA)

Combinations of polymer based impregnation were applied on different batches of RCA.

A screening of polymer based treatment were used and applied with concentration gradient on RCA in order to know the impact on water absorption capacity of RCA treated (Moze and BO).

Simple and double combinations were practiced. The water coefficient was determined after 48h of total water immersion. The ratios of initial water absorption per final absorption were calculated for each composition.

- Siloxane and silane based effect on the water absorption of RCA treated.

The following graph (see Fig. 3) shows the water absorption coefficient ratio between recycled concrete aggregates untreated and treated in function of P1 and P0 treatments. The impact of P1 impregnation (only) can be observed up to 30% (in concentration). It ratio of initial absorption per final absorption is 4 times lower than the reference one. So this kind of treatment implies a significant reduction of water absorption capacity. The impact is reinforced by adding P0 treatment. In this case, the double combination (P0+P1) allow reducing water absorption coefficient from 6 to 7 times than the reference depending of the recycled concrete aggregates type. These RCA treated (P0+P1) absorb less than 20% compared with the initial water absorption of RCA untreated (reference).

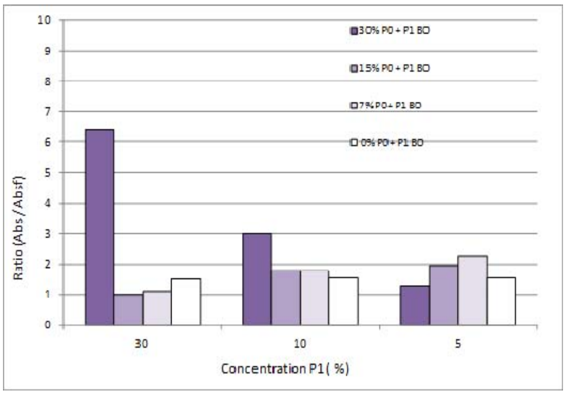

Fig. 3 Water absorption coefficient ratio (48h) between untreated recycled (reference) and recycled concrete aggregates versus P0 and P1 concentration by P0 and P1 applied on BO recycled concrete aggregates with 12-20mm fraction

- Silane-based only effect on the water absorption of RCA treated

Fig. 4 gives the water absorption coefficient ratio in function of the concentration of P0 and P2.

By screening concentration of P2, the polymer based treatment was applied on RCA. The presence of an optimum concentration was observed. This kind of treatment becomes efficient up to 30% (in concentration) and allows reducing the water uptake. The PI-RCA (treated only by P2) absorbs 4 times less than RCA reference. The water absorption of RCA treated represents 80% less than RCA reference. Results show clearly that RCA treated with a silane-based emulsion (P2) are absorbing much less water than the reference (recycled concrete aggregates without any treatment). In spite of second impregnation, the composition containing sodium silicate (P0) and silane emulsion (P2) do not change their resistivity against to the water penetration in their porous network while the compositions containing only silane agent (P2). In this case, no significant impact of combining these 2 polymers based treatment (P0+P2) compared with combination 1 (P0+P1). The silane based emulsion applied on RCA diminishes 2 to 9 times water absorption coefficient than the reference.

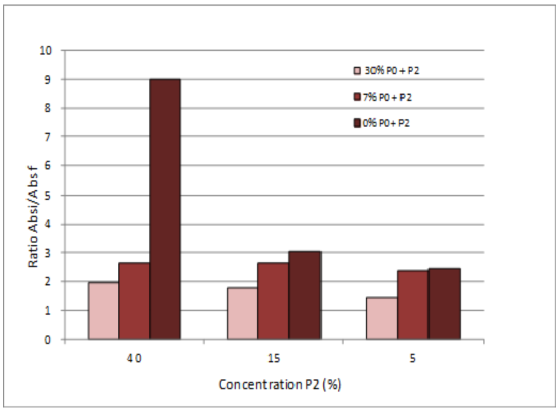

Fig. 4 Water absorption coefficient ratio (48h) between untreated recycled concrete aggregates (reference) and recycled aggregate treated versus P0 and P2 concentration by P0 and P2 applied on BO recycled concrete aggregates with 12-20mm

C. Comparison of Water Absorption between Untreated (RCA) and Treated Recycled Concrete Aggregates (PI-RCA)

Fig. 5 sums up the all different combination practiced versus the water absorption coefficient ratio. These polymer based treatments were used on two kind of recycled concrete aggregates (Moze and BO). These results show the positive effect induced by polymer treatments of water absorption capacity of RCA. In addition, the polymer treatments appear to be an appropriate treatment on RCA.

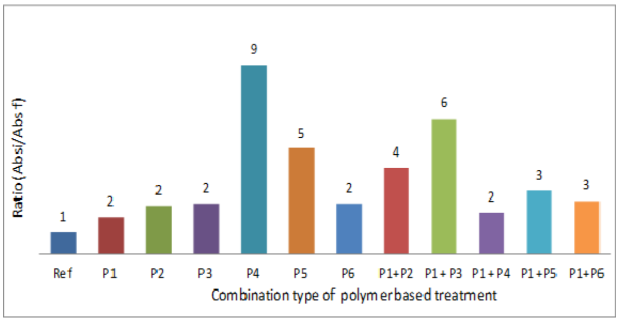

Fig. 5 Effect of different combinations of polymer based treatments (Px) on water absorption coefficient ratio (48h) between untreated recycled aggregates (reference) and recycled aggregates treated with 12-20mm fraction

Impregnation of masonry with water repellent based emulsions particularly with siloxane and/or silane polymers appears to be the most successful method of protection from capillary water absorption. This kind of water repellent treatment already used as surface treatment for construction materials [17-18]. Both treated RCA type by combining polymers are efficient.

TABLE II
LA COEFFICIENTS VS GRANULAR FRACTION ON NATURAL AGGREGATES, RCA AND TREATED RCA

Aggregates type	Los Angeles (LA) coefficients (%)	
Natural aggregates	4-12mm	12- 20mm
Boulonnais	23-24	23-24
Recycled concrete aggregates	4-12mm	12- 20mm
BO	25±3	27±2
BO treated by P0 +P1	24±3	22±2

These kinds of treatments imply the formation of polymeric film. This polymeric film, developed by combining two polymers based treatment, should also provide an effect of consolidation on recycled concrete aggregates. The polymeric film developed, by combining two polymers, supply water repellent performance which decreases significantly water absorption and reinforcing cement matrix of RCA. This means that recycled concrete aggregates especially adhered mortars are protected against water penetration. In particular, this layer could change pore network especially the part of primary adhered mortar but no significant impact on porosity was detected by MIP. In addition, Los Angeles measurements (see Table II) were carried out and show the impact of combination of polymers on toughness resistance. The Los Angeles coefficient of RCA treated is better than the reference.

V. CONCLUSION

Set of polymers are screening to find out an efficient chemical polymer based treatment in order to improve RCA properties. Concentration gradient and combination of polymer treatments were practiced. Kinetic differences of saturation between recycled concrete aggregates (RCA) and natural aggregates have been identified. Their maximum saturation of RCA is only reached beyond 24 hours.

The general trend is an improvement of the water absorption resistance. The first results are very encouraging and confirm the interest of this kind of appropriate treatment.

The polymeric film developed in the pore network allows the significant reduction of water absorption capacity. Water repellent performance is achieved on RCA treated.

The film formed is efficient and resistant in alkali environment. The polymer based treatments are easy to prepare. This treatment should be tested on other concrete aggregates and other granular fraction.

Physical and chemical interaction should be studied in order to understand better the mechanism induced by the polymer treatment on RCA as well as the durability of PI-RCA and new concrete containing PI-RCA. In addition, the RCA treated by these kind of polymer treatment in future mix design, could be useful to the workability and water retention abilities.

New concrete containing RCA treated will be studied in order to show the relevance of the treatments.

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