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# Effect of self-cementing properties on pavement deflection with recycled concrete aggregate

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**Abstract.** Recycled concrete aggregates (RCA) are increasingly being used as unbound granular materials (UGM) in low-traffic pavement base and subbase layers, while the effect of self-cementing properties of RCA on the long-term performance of RCA and pavement, built with RCA, has not been thoroughly studied. In this paper, the effect of self-cementing properties on the resilient deformation behaviour of RCA, after curing for different times (1, 180, 360 and 720 days), were studied by repeated load triaxial tests (RLTT). Then, the deflection of a low-traffic pavement structure, built with RCA, was investigated by finite element modelling. The results indicate that the resilient deformation behaviour of RCA improves with curing time, which is similar to that of lightly bound materials, due to the self-cementing properties. As a result, the deflection of a low-traffic pavement structure, built with RCA, decreases with curing time, showing the good long-term performance of RCA.

**Keywords:** Recycled concrete aggregates, Repeated load triaxial tests, Pavement deflection.

## 1 Introduction

Concrete wastes are the main components of construction and demolition wastes (CDW), representing up to 75% of total CDW [1]. In 2018, over 800 million tonnes of CDW were produced in Europe [2]. Recycling and reuse of concrete wastes in unbound pavement base and subbase layers, as a substitution for scarce natural aggregates, has been considered as a practical way to achieve a sustainable development of road construction [3, 4].

Sometimes, an increase of strength and stiffness of unbound base layers, built with recycled concrete aggregate (RCA), can be observed after construction (Arm, 2001; Wang et al., 2023), known as self-cementing properties of RCA. The hydration of unhydrated cement in RCA fine aggregates, exposed by the crushing process, is believed to be the primary cause of self-cementing properties. The self-cementing properties of RCA have a significant impact on their mechanical behaviour [5-7], while

the effect of self-cementing properties on the long-term performance of RCA and on the design of pavement have been rarely studied.

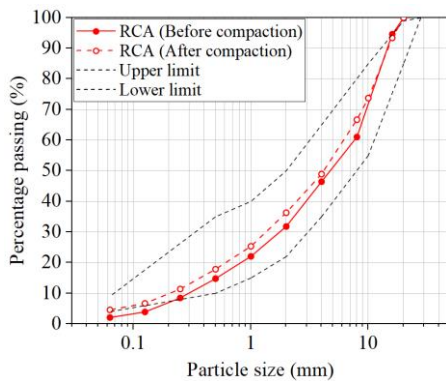
The aim of this paper is to study the effect of self-cementing properties on the long-term performance of RCA materials and pavement, built with RCA. The effect of self-cementing properties on the long-term performance of RCA, after curing for different times (1, 180, 360 and 720 days), was studied by conducting a series of repeated load triaxial tests. A finite element modelling was finally performed on a low-traffic pavement structure, built with RCA after curing for different times, to take into account the effect of self-cementing properties on the long-term mechanical behaviour of low-traffic pavement.

## 2 Materials and methods

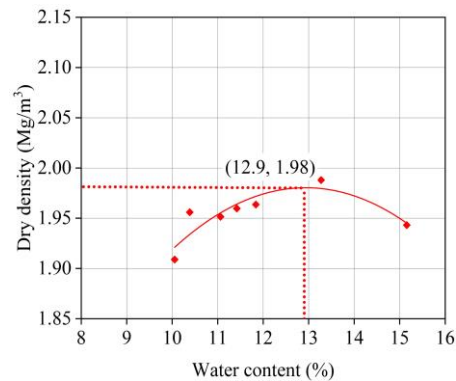
### 2.1 Materials

The used RCA materials were sourced from demolished buildings and were crushed at the beginning of the study in 2020, in the recycling plant in Strasbourg, France, representing the typical available RCA.

Fig. 1 presents the particle size distributions of the RCA before and after compaction for sample preparation. The curves show that some weak particles break during the compaction process, increasing the fines content which is believed to be the primary cause of self-cementing properties. The maximum particle size is 20mm. Fig. 2 shows the Modified Proctor curve of RCA. The optimum moisture content (OMC) and the maximum dry density (MDD) of RCA are 12.9% and 1.98 Mg/m<sup>3</sup>, respectively. More detailed information can be found in Wang et al. [8].



**Fig. 1.** Particle size distributions of RCA before and after compaction.



**Fig. 2.** Modified Proctor curve of RCA.

## 2.2 Specimen preparation and repeated load triaxial test

Specimens for the repeated load triaxial tests were prepared using a standard procedure [9], at the same water content (OMC-1%) and same dry density (optimum dry density at the targeted water content), which were 11.9% and 1.97 Mg/m<sup>3</sup> selected from the Modified Proctor curve (Fig. 2). Each sample, with a diameter of 150 mm and a height of 300 mm, was compacted in a split mould to the targeted dry density by a vibrating hammer, in 7 layers. Finally, the specimens were demolded, wrapped in plastic bags, and stored indoors for 1, 180, 360 and 720 days at a temperature of 18±5 °C, before testing.

The repeated load triaxial tests (RLTT) were performed to study the influence of self-cementing properties on the resilient deformation behaviour. The specimen, after curing, was subjected to a conditioning phase firstly to stabilize the permanent deformation. Then, resilient behaviour was studied with 5 different stress paths ( $\Delta q/\Delta p=0, 1, 1.5, 2$  and  $2.5$ ), under high stress level (NF EN 13286-7, 2004), as shown in Fig. 3. The resilient behaviour was presented in terms of resilient deviatoric strain ( $\epsilon_q^r$ ) and resilient volumetric strain ( $\epsilon_v^r$ ). The water content of tested sample was measured to make sure that no water evaporation has occurred in the curing stage.

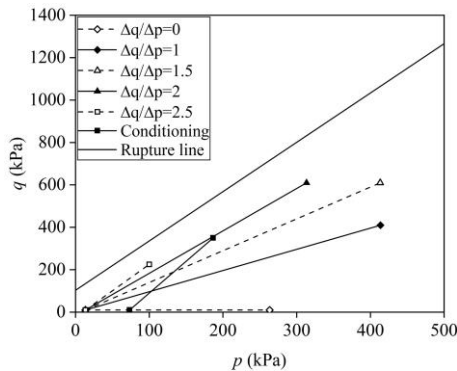


Fig. 3. Stress paths for repeated load triaxial tests.

## 3 Resilient behaviour

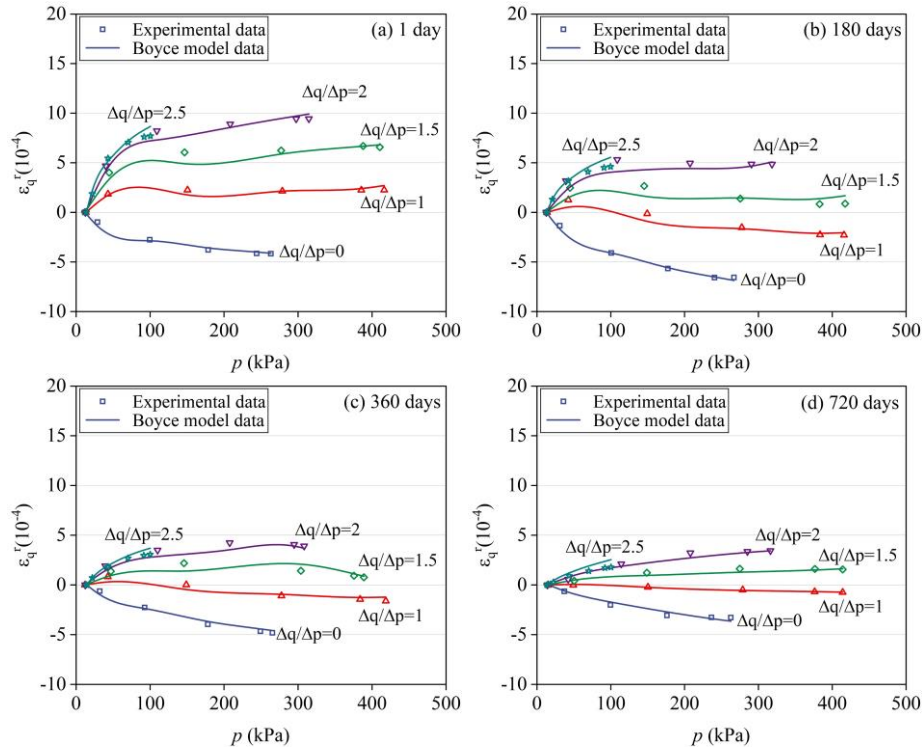
Fig. 4 and Fig. 5 depict the resilient deviatoric strains  $\epsilon_q^r$  and volumetric strains  $\epsilon_v^r$  of the studied RCA, for different stress paths  $\Delta q/\Delta p$ , after curing for different times. It can be observed that the resilient behaviour of RCA is strongly non-linear and depends on the stress path  $\Delta q/\Delta p$ , as  $\epsilon_q^r$  increases while  $\epsilon_v^r$  decreases with increasing stress ratio  $\Delta q/\Delta p$ , in agreement with those of unbound granular materials (UGM).

For the effect of self-cementing properties,  $\epsilon_q^r$  and  $\epsilon_v^r$  decrease as curing time increases (especially after 360 days), and become linear and less stress-dependent. Note that the resilient behaviour of UGM is strongly non-linear and stress-dependent [10], while it is not a property of bound materials [11]. These results indicate that the

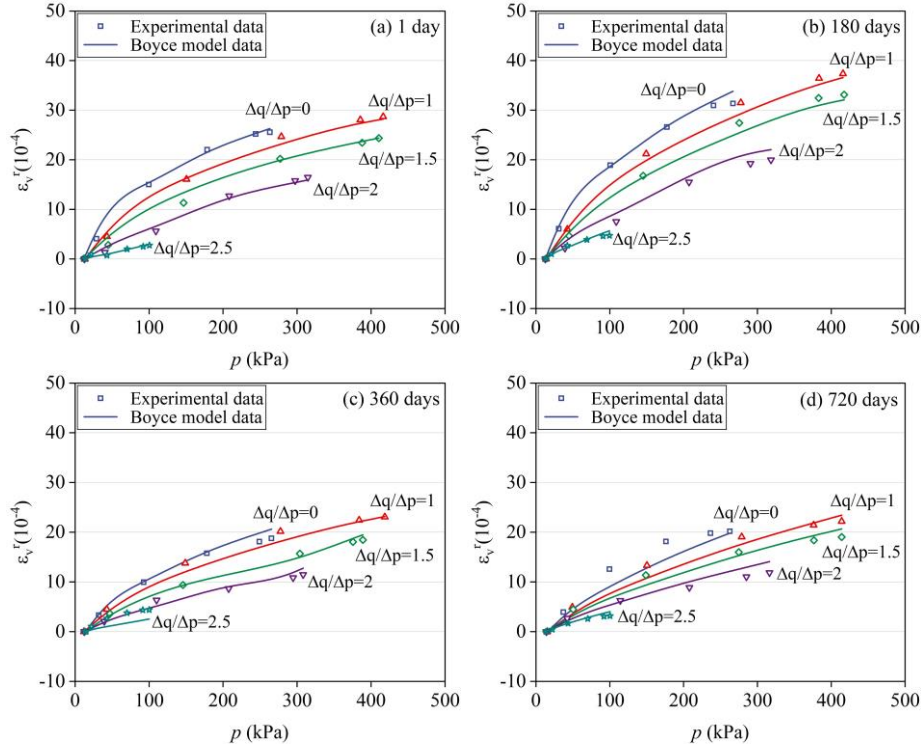
unbound RCA specimens (curing for 1 day) have gradually evolved into (partially) bound specimens (like curing for 360 days) after long-term curing.

To simulate the deflection of pavement built with RCA, the modified Boyce model [8, 12] was used to model the mechanical behaviour of RCA after curing for different times. Table 1 summarizes the parameters of modified Boyce model of RCA after curing for different times, and the comparisons between experimental and modelling results were presented in Fig. 4 and Fig. 5. It shows that the modified Boyce model can describe the resilient deformation behaviour of RCA well, as indicated by the good correlation coefficients ( $CC > 0.8$ ).

It should be noted that parameters  $K_a$  and  $G_a$  are related to the bulk and shear moduli. It can be observed that parameters  $K_a$  and  $G_a$  increase with curing time, and then tend to stabilize, indicating the improvement of resilient behaviour of RCA due to the self-cementing properties. Table 1 also summarizes the parameters of UGM reported by Chazallon et al. [13]. The material characteristics of RCA and UGM are presented in Table 2. It shows that parameters  $K_a$  and  $G_a$  of UGM are lower than those of RCA curing for 1 day, showing the good performance of RCA compared with the reported UGM.



**Fig. 4.** Evolution of resilient deviatoric strains  $\varepsilon_q^r$  of RCA for different stress paths  $\Delta q/\Delta p$ , curing for different times: (a) 1 day; (b) 180 days; (c) 360 days and (d) 720 days.



**Fig. 5.** Evolution of resilient volumetric strains  $\varepsilon_v^r$  of RCA for different stress paths  $\Delta q/\Delta p$ , curing for different times: (a) 1 day; (b) 180 days; (c) 360 days and (d) 720 days.

**Table 1.** Modified Boyce model parameters of RCA after different curing times, UGM and soil (Missillac sand) [13].

| Materials       | Curing days | $K_a$ /MPa | $G_a$ /MPa | $n$   | $\gamma$ | CC   |
|-----------------|-------------|------------|------------|-------|----------|------|
| RCA             | 1           | 31.06      | 49.49      | 0.35  | 0.69     | 0.89 |
|                 | 180         | 26.98      | 52.22      | 0.41  | 0.58     | 0.87 |
|                 | 360         | 50.82      | 99.41      | 0.45  | 0.68     | 0.86 |
|                 | 720         | 51.79      | 102.91     | 0.53  | 0.54     | 0.83 |
| UGM*            |             | 20.1       | 39         | 0.351 | 0.52     |      |
| Missillac sand* |             | 24.9       | 30.6       | 0.514 | 0.64     |      |

\*Note: data from Chazallon et al. [13].

**Table 2.** Material characteristics of RCA, UGM and Missillac sand [13].

| Materials      | Particle size | OMC  | MDD                | Water content | Degree of compaction |
|----------------|---------------|------|--------------------|---------------|----------------------|
|                | /mm           | /%   | /Mg/m <sup>3</sup> | /%            | /%                   |
| RCA            | 0-20          | 12.9 | 1.98               | OMC-1%        | 99                   |
| UGM            | 0-20          | 6.3  | 2.17               | OMC-2%        | 97                   |
| Missillac sand | 0-4           | 9.2  | 2.04               | OMC+2%        | 97                   |

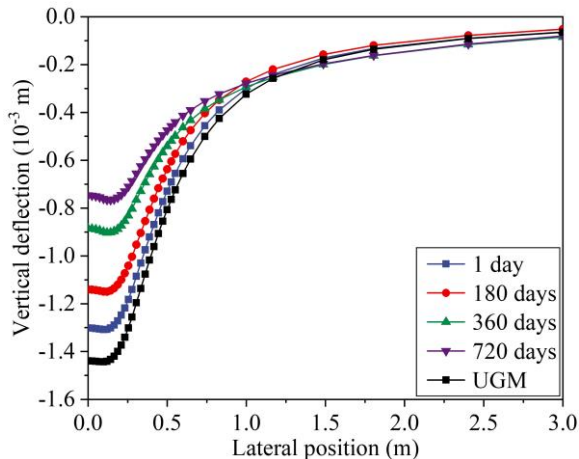
## 4 Numerical simulation

To illustrate the effect of self-cementing properties on the deflection of low-traffic pavement structure, whose base layer is built with RCA, a finite element modelling was performed using CAST3M [14]. The low-traffic pavement structure consists of an asphalt concrete layer with a thickness of 6.6 cm, a thickness of 50 cm granular base layer built with RCA or UGM, and a subgrade (Missillac sand) with a thickness of 220 cm [13, 15].

The mechanical parameters of asphalt concrete layer and subgrade (Missillac sand) were obtained from [13] and [15]. The behaviour of asphalt concrete is assumed linear elastic, where the Young modulus is equal to 6110 MPa, determined in situ conditions, and its Poisson ratio is taken equal to 0.35. The behaviour of granular base layer (built with RCA or UGM) and subgrade (Missillac sand) are calculated by modified Boyce model, as summarized in Table 1.

A 3D finite element calculation is carried out on a quarter of the structure. The applied load was a 65 kN dual wheel load (32.5 kN per wheel), representing the French standard single axle load, and the loading speed was 72 km/h. The loading area is made of two rectangles, where each has a length of 0.30 m and a width of 0.18 m.

Fig. 6 shows the deflections of the low-traffic pavement structures built with RCA, after curing for different times, and UGM. It can be observed that the vertical deflection of pavement structures built with RCA decreases with the increase of curing time, especially after curing for 360 days, since unbound RCA materials (curing for 1 day) have gradually evolved into (partially) bound materials after curing for 360 days, as indicated in Fig. 4 and Fig. 5. After curing for 720 days, the deflection of pavement structures is much lower than that curing for 1 day, showing the great improvement of pavement performance built with RCA after construction. For pavement structures built with UGM, it shows the highest vertical deflection compared with those built with RCA, since RCA materials show better mechanical behaviour as observed in Table 1.



**Fig. 6.** Comparison of finite element calculation of the vertical deflection of low-traffic pavement structure, built with RCA materials after curing for different times and built with UGM.

## 5 Conclusion

In this study, the influence of self-cementing properties of RCA on its resilient deformation behavior and on the deflection of a low-traffic pavement structure, built with RCA, was investigated, by conducting a series of repeated load triaxial tests and finite element modelling.

The results of repeated load triaxial tests showed that the mechanical behaviour of RCA increases with curing time, as resilient deviatoric and volumetric strains decrease with curing time. The unbound RCA specimens (curing for 1 day) have gradually evolved into (partially) bound specimens after curing for 360 days, whose resilient behaviour is linear and less stress-dependent.

The modelling results showed that the vertical deflection of low-traffic pavement, built with RCA, decrease with the increase of curing time. The effect of self-cementing properties of RCA on the deflection of pavement structure is more pronounced after curing for 360 days, when unbound RCA materials (curing for 1 day) have gradually evolved into (partially) bound materials after curing for 360 days.

Based on those experimental and modelling results, it is found that the performance of RCA, used as unbound granular materials in pavement, increases with curing time, and is similar to that of bound materials after long-term curing. As a result, the deflection of low-traffic pavement, built with RCA, decreases largely after long-term curing, encouraging the use of RCA in low-traffic pavement.

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