Construction and Building Materials 108 (2016) 163–174

Contents lists available at ScienceDirect

Construction and Building Materials

journal homepage: www.elsevier.com/locate/conbuildmat

Relationships between recycled concrete aggregates characteristics and recycled aggregates concretes properties

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HIGHLIGHTS

- Physical and mechanical properties of recycled concrete aggregates.
- The frost resistance of aggregates subjected to freezing/thawing cycles in water.
- Prediction of the properties of aggregates whatever their origins by Voigt's model.
- Establishment of relationship between the properties of concrete and those of gravels.

ARTICLE INFO

Article history:
Received 28 October 2015
Received in revised form 21 January 2016
Accepted 26 January 2016
Available online 5 February 2016

Keywords:
Recycled concrete aggregates (RCA)
Recycled aggregates concretes (RAC)
Physical and mechanical properties of aggregates
Freezing/thawing of aggregates
Mechanical properties of concrete

ABSTRACT

This research aims to analyze the quality and suitability of recycled concrete aggregates (RCA) produced by crushing concrete blocks provided from building demolition waste by comparison to natural ones in providing concretes for building structures. For each granular type, sieving, water absorption, porosity, Los Angeles and Micro-Deval tests were conducted before and after their exposure to freezing/thawing. Results show that the rules of mixtures (Voigt's model) can be used to predict all the studied properties of granular mixes (natural gravels + recycled gravels) except for the prediction of Micro-Deval index. Relationships are established between physical and mechanical characteristics of aggregates. The analysis of the frost resistance performance show that recycled concrete gravels are less resistant to freeze/thaw than natural one but their degradation, estimated through water absorption, porosity and Micro-Deval index, is not significant. Furthermore, the influence of RCA on mechanical properties of recycled aggregates concretes (RAC) is investigated. It appears that porosity and young's modulus of RAC are significantly affected by the porosity of the granular mixture and consequently of RCA. The compressive strength of RAC is dependent on the Los Angeles coefficient of gravels while tensile splitting strength depends on the porosity of concretes related to that of the granular mixture.

1. Introduction

Development in many sectors has negative environmental effects. In construction sector, there are millions of tonnes of construction and demolition waste (CDW) every year. This CDW has a significant damage on the environment and may endanger its sustainability. To find a conceivable solution for CDW and to preserve the natural resources, particularly the non-renewable ones, worldwide researches on recycled aggregates have been increased in order to investigate their revalorization possibilities in concretes.

The CDW can cover a wide range of materials, which depend on their origins: total or partial demolition of infrastructure, construction of buildings, land leveling excavation, civil works and/or general foundations and road maintenance activities [1]. An estimated 900 millions of tonnes of CDW is generated every year in Europe, USA and Japan as reported by the World Business council for Sustainable Development [2].

The review of selected waste streams by European Environmental Agency [3] presents the annual quantity of CDW produced by European countries and explains the considerable difference between countries in producing waste materials due to some characteristics of industrials and institutional activities. Moreover, it appears clearly that the trends in CDW disposal and recovery in Europe differ from one country to another. France, Germany, United Kingdom and Italy produce 74% of all CDW where France,

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http://dx.doi.org/10.1016/j.conbuildmat.2016.01.042
0950-0618/

with a ratio of 5.5 tons of waste/person per year, is at the higher level [3–6]. Furthermore, 2.6 million tons of fresh concrete are considered as waste and should be recycled in this country [6,7].

As many developed countries, France also has introduced legislations and strategies to reduce the environmental effects of CDW. Corresponding to problem of CDW, there are two national project called PN-RECYBETON [8] and ANR VBD2012-ECOREB [9] that deal with how to provide concretes for building field using aggregates provided from CDW.

In order to valorise waste materials derived from the demolition of buildings and to preserve consequently the natural resource, a national project, called PN-RECYBETON, was initiated in France in 2012 for 5 years. PN RECYBETON aims to provide recommendations and technical specifications for a possible use of the building demolition wastes as aggregates in building construction projects. The recycled concrete aggregates, RCA, must be widely used to produce new concretes and therefore can be considered as new environmental, economic and technological perspectives.

In parallel to PN RECYBETON another national research project named ECOREB and financed by the national agency of research, ANR was started in 2013 to remove academic and scientific issues which are addressed in PN RECYBETON. ECOREB project is structured around three areas of research: water and recycled materials, mechanical behavior of concrete with recycled concrete aggregates and durability of concretes with RAC. The objectives are to develop methodologies and models to predict the behavior of fresh recycled aggregates concretes (RAC), the plastic shrinkage, the mechanical and fracture behavior of the hardened recycled aggregates concretes (RAC), to develop relationships between the mechanical properties of RCA and RAC and to evaluate the influence of RCA on the performance of concrete durability.

This research is done in the framework of ANR-VBD2012-ECOREB.

Aggregates represent about 70–80% of concrete components. Accordingly, the properties of concretes are directly dependent on the physical and mechanical properties of aggregates. In the literature, most of the researches deal with the influence of the partially or totally substitution of natural gravels by recycled ones on some characteristics of concretes [10–17]. Few of them attempt to propose relations that link the properties of RCA to the strength of RAC [18] or to examine the effect of attached cement mortar content on the properties of recycled aggregates [19].

Hence, this paper presents a detailed research on physical and mechanical properties of natural aggregates, called NA, and recycled concrete ones, designed as RCA produced by crushing concrete blocks provided from building demolition waste. This work aims particularly to

- Check the validity of tests conducted according European standards and those required for the characterization of RAC (water absorption, density, porosity, ...).
- Develop relationships between the water absorption coefficient of aggregates and the others properties independently of the origin and nature of aggregates.
- Ensure that mixture laws allow the prediction of the properties of the granular mixtures (NA + RA).
- Study the frost resistance of recycled and natural gravels and the effect of the old paste on this resistance.
- Develop relationships between the mechanical properties of RCA and mixing parameters and those of RAC.

The proposed relationships are established on the basis of experimental results of this research and data got from the analysis of literature. Hence, proposed models cover a wide range of sources of aggregates.

2. Materials

The NA and RCA were provided by PN-RECYBETON [8]. NA is classified as coarse natural gravels (NG2), fine coarse natural gravels (NG1) and natural sand (NS). The recycled aggregates were produced in a platform of recycling by crushing concrete waste of demolished buildings. They are composed of old paste and natural aggregates and are free of other materials like bitumen. Three granular fractions are considered: coarse recycled gravels (RG2), fine coarse recycled gravels (RG1) and recycled sand (RS) (Table 1). A Portland cement (CEM II/A-L 42.5) and limestone filler (HP-OG) with densities of 3.09 and 2.7 respectively are used. The compressive strength of the cement at 28 days is about 51.8 MPa [8]. To ensure a high workability of all developed mixes, a superplasticizer, MC Power-Flow 3140, was employed.

3. Experimental methods

In order to determine the physical properties of aggregates, all fractions of NA and RCA were separately subjected to sieving, density, water absorption and porosity tests.

To define the size distribution of NA and RCA, the sieving was carried-out according to NF EN 933-1 [20]. It has been observed that, both NG and RG have approximately the similar size distribution (Fig. 1). However, grading curves indicate that RS is containing much fine fraction (<2 mm sieve) than NS. This can be critical for the concrete mix design.

The water absorption (WA) is an important physical property of aggregates. Hence, it was determined by means of three methods. The first one is the pycnometer method according to standard NF EN 1097-6 [21]. The second one is the method of hydrostatic weighing continuously (HWC) used to follow the evolution of mass change of aggregates during their immersion in water. In this method a balance is linked to a computer so that the evolution of the mass is recorded continuously.

The third method obeys to the French standard NF P 18-459 [22]. The gravels are placed in an airtight container and vacuum is created until reaching a pressure of 25 mbar. The vacuum is maintained for 4 h at this pressure. The gravels are, then, weighed (M_w) after being submerged in water at different duration (24 h, 48 h...). After being taken out of container they are weighed (M_{air}) then dried at $105^{\pm5}$ °C until reaching a constant mass (M_{dry}). The porosity (n) as well as the coefficient of water absorption (WA) are calculated using Eq. (1) and Eq. (2):

$$\text{Coefficient of water absorption} \quad \text{WA}(\%) = \frac{M_{air} - M_{dry}}{M_{dry}} \times 100 \qquad (1)$$

$$\text{Porosity} \quad n(\%) = \frac{M_{air} - M_{dry}}{M_{air} - M_w} \times 100 \qquad (2)$$

where M_{air} is mass of gravels sample at the saturated surface-dried state, M_{dry} is the mass of gravels sample at oven dried state and M_w is the mass of gravels sample in water.

To assess the mechanical properties of gravels, Los Angeles test is conducted according to NF EN 1097-2 [23] in order to determine their resistance to fragmentation and Micro-Deval test is applied according to NF EN 1097-1 [24] to check their resistance to wear.

The durability of gravels regarding to freezing/thawing cycles is considered according to NF EN 1367-1 [25]. The mass loss (F) of the

Table 1
The fractions of NA and RA.

Aggregates	Codes	Grading (mm)
Natural sand	NS	0–4
Natural gravels	NG1	4–10
	NG2	6.3–20
Recycled sand	RS	0–4
Recycled gravels	RG1	4–10
	RG2	10–20