Construction and Building Materials 164 (2018) 57–69

Contents lists available at ScienceDirect

Construction and Building Materials

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

Functional and structural parameters of a paved road section constructed with mixed recycled aggregates from non-selected construction and demolition waste with excavation soil

Javier Tavira [a,*,1], José Ramón Jiménez [b,*,1], Jesús Ayuso [b], María José Sierra [c], Enrique Fernández Ledesma [d]

[a] JTD Civil Eng., Carretera de Carmona 40 D 1°, D 41008 Sevilla, Spain
[b] Área de Ingeniería de la Construcción, Universidad de Córdoba, Ctra. N-IV, Km 396, 14014 Córdoba, Spain
[c] Agencia de la Obra Pública, Consejería de Fomento y Vivienda, Junta de Andalucía, Av. Diego Martínez Barrio, 10, 41013 Sevilla, Spain
[d] Área de Mecánica de Medios Continuos y Teoría de Estructuras, Universidad de Córdoba, Ctra. N-IV, Km 396, 14014 Córdoba, Spain

HIGHLIGHTS

- A road test track was built to evaluate the long-term performance of RA.
- Comparative study for Moduli calculation of RA and NA layers was carried out.
- Back and forward calculation was performed using deflections from a HWD.
- Regularity of the road showed a well evolution after seven years open to traffic.
- Results showed that RMA and RMAS can replace NA in low traffic roads construction.

ARTICLE INFO

Article history:
Received 15 May 2017
Received in revised form 6 December 2017
Accepted 27 December 2017

Keywords:
Construction and demolition waste
Mixed recycled aggregates
Backcalculation
Forward calculation
International roughness index
Experimental road

ABSTRACT

This paper evaluates the lab and in situ mechanical properties of non-selected mixed recycled aggregates from construction and demolition waste (CDW) used as base and subbase unbound materials. Excavation materials are mixed with CDW to produce recycled mixed aggregates with soil, as well as a finer material referred to as mixed recycled soil. The research was divided into two different stages: a laboratory study characterizing the properties of recycling aggregates and a road test track evaluating the long-term performance of these materials under real traffic and weather conditions. During construction, several density, plate load, and falling weight deflectometer tests were performed to determine the bearing capacity of all layers. A laser profiler was also used to obtained the international roughness index. After the road was opened to traffic, a follow up of deflections and surface roughness was performed during the following seven years.

Two different moduli calculation methods were used: back calculation and forward calculation. Both methods shown acceptable values for these recycled materials. Low quality recycled mixed aggregates can be used as substitutes for natural aggregates as unbound layers. The mechanical performance and surface roughness values obtained from the experimental road shown an acceptable behaviour.

1. Introduction

The construction sector contributes significantly to greenhouse gas emissions because of the use of heavy machinery and because of cement production; these emissions contribute greatly to climate change (UE Directive 2010/31/EC). Additionally, construction activities consume a large quantity of non-renewable natural resources, such as aggregates, which are scarce in many countries. To reduce these negative effects and contribute to the sustainability of the sector, it is necessary to promote the use of recycled

Abbreviations: CDW, construction and demolition waste; RMAS, recycled mixed aggregates with excavation soil; MRS, mixed recycled soil; FWD, falling weight deflectometer; IRI, international roughness index; NA, natural aggregates; RA, recycled aggregates; RCA, recycled concrete aggregates; CBR, California bearing ratio; ER, experimental road; NDT, nondestructive testing; CS, crushed stone; SS, selected soil; SG, subgrade; GPR, ground penetrating radar; PG3, Spanish general technical specification for road construction.

* Corresponding authors at: Construction Engineering Area, University of Córdoba, Ed. Leonardo Da Vinci, Campus de Rabanales, Ctra. N-IV, km-396, CP 14014 Córdoba, Spain.

E-mail addresses: jtavira@ciccp.es (J. Tavira), jrjimenez@uco.es (J.R. Jiménez).

[1] Both authors equally contributed to the paper.

https://doi.org/10.1016/j.conbuildmat.2017.12.195

aggregates (RA) from construction and demolition waste (CDW). This will provide a second life cycle to raw materials [1].

In 2009 approximately 530 million tonnes of CDW were produced in the European Union [2]. Spain produced 26 million tonnes in 2012 [3]. If the excavation soils from construction activities were included, the total waste would be 1350–2900 million tonnes [4]. These data show the importance of CDW and excavated soils to waste generation. According to the European Commission, 25–30% of total generated solid waste comes from construction. The recycling rate in Spain reached 30% in 2011 [5], which is below the EU-27 average (47%) [5] and it much lower than that in other European countries such as Germany (86%) or Denmark (94%) [2]. The waste framework directive of the European Parliament on waste stipulated that by 2020, a minimum recycling level must be achieved of 70% of non-hazardous CDW [6].

The possibility of using RA from CDW in road construction has been studied by many researchers. Vegas et al. [7], Garcia [8], Poon et al. [9] and Jiménez et al. [10–12] assessed the feasibility of using RA as a granular material in the structural layer of pavement. Vegas et al. [7] and Jiménez et al. [10–12] concluded that the most critical properties are sulphur content because it can generate dimensional unstability of the layer and fragmentation resistance which is deeply related with durability. Jiménez et al. [10–12] compared the behaviour of RA from CDW with that of natural aggregates (NA) on unpaved rural roads. They concluded that RA can be used as an alternative to NA on unpaved roads. Few studies on the mechanical capacity of RA have been made on experimental road sections [13].

In a laboratory study, Del Rey et al. [14] found that cement-treated RA in a size range of 0–8 mm can be used as a subbase layer for light-traffic roads. Agrela et al. [15] performed tests on a road section constructed with recycled mixed aggregates (RMA) in Malaga (Spain), and concluded that RMA treated with 3% cement can be used in the subbase layers of roads. Perez et al. [16] used recycled concrete aggregates (RCA) and natural aggregates (NA) treated with cement as sub-base layers in two road test sections. Deflections showed that RCA had a higher bearing capacity although a higher percentage of water was needed.

Cardoso et al. [17] reviewed the use of RA in geotechnical applications, mainly the use of CDW in pavement layers. Several studies were performed on pavements made with NA, RCA, and RMA; these produced several conclusions regarding the bearing capacity, durability, and workability of RA relative to NA. The international roughness index (IRI) and deflections were similar in both materials, with RA performing better. RMA and RCA have a higher optimum water content than NA. The Californian bearing ratio (CBR) of RMA was lower than that of NA, but it could be increased by adding RCA.

There has been some international experience with RMA and RA used in low volume traffic roads. In China [18], RA obtained from concrete and bricks waste was used in bases and sub-bases. Cement was added, and deflection tests were made comparing RMA and RCA stabilized with cement and limestone. The main conclusion was that RA treated with cement are feasible for road pavement construction.

Park [19] used two road sections constructed from variable-quality RCA and compared them with those constructed from NA, obtaining similar deflections. Lancieri et al. [20] performed a long-term test using RMA as an unbound layer in two paved sections, obtaining elastic moduli for these recycled unbound layers over a period of eight years. These materials showed an increase in bearing capacity due to self-cementing and further traffic compaction.

The elastic modulus is a basic input needed to calculate stress–strain values for pavement. Mechanical durability is deeply connected with this parameter.

This paper has two main purposes. The first one is to study the short and long-term performance of low quality recycled materials obtained from non-selected CDW mixed with excavated soils. The second one is to calculate the elastic moduli of these materials in an experimental road (ER) using nondestructive testing (NDT) such a FWD. The elastic modulus of each layer can be determined using the deflection basin [21]. This way, the mechanical properties of these materials can be obtained, assuring the bearing capacity of the road.

Because of the high amount of excavated soil obtained from construction sites [4,13], it is quite important to find new applications for these wastes. To the best of the authors' knowledge, there are no previous studies investigating RA mixed with excavated soils and used as unbound layers in roads. RMA with soil (RMAS) could also be a good material for reducing plasticity of the excavated wastes, because RA has no expansive properties [13]. To test the viability of RA used in unbound layers in road pavements, it is critical to reproduce real scale models. It is fundamental to perform middle- and long-term evaluations to verify the consistency of RA in these uses. Because of the duration of the present study, this target has been achieved. It also fills a gap in the availability of long-term performance studies on recycled materials used in roads open to traffic.

2. Materials and methods

2.1. Description of test sections

The experimental road (ER) was built on the service road of a four-lane freeway in Seville (south of Spain). The ER consists of three sections, each one 150 m long (total length of 450 m). Fig. 1 shows a description of the three sections and the thicknesses of the structural layers. The surface course for all sections consists of 5 cm of asphalt concrete. The base course of the first two sections is a crushed limestone (CS-1) used as a reference and a recycled mixed aggregate from non-selected CDW with excavation soil (RMAS-1). In the third section, granular base course materials would be classified as a A1a, according to AASHTO [22]. The sub-base course was built with two different materials, a natural selected soil, which would be classified as A3 according to AASHTO [22] (SS-1), and a mixed recycled soil (MRS-1) from preliminary screening in Sections I.II and I.III, which would be classified as A4 [22]. Construction of the ER lasted from February to June of 2009.

The two basic characteristics of this road are as follows:

- Traffic intensity is homogeneous for all sections investigated. Traffic counting was performed from the September 5th 2016 (Monday) to September 11th 2016 (Sunday). The mean value for heavy vehicles was 30 per day, from a total of 659. According to Spanish standards [23] this road would be classified as a T41 (25–49 heavy vehicles/day).
- The subgrade has the same composition in the three sections. It is a red silty clay, classified as A6 in accordance with AASHTO [22] (SG-1).

2.2. CDW treatment process

Two recycled materials (MRS-1 and RMAS-1) were collected from a recycling plant located 5 km north of the ER (Sevilla, Spain). Fig. 2 shows a schematic of the process followed to obtain both recycled materials. MRS-1 was obtained from the preliminary screening process (20 mm sieve) of a non-selected CDW mixed with excavation soils. The excavated soil came from construction sites around the recycling plant, basically this material came from foundations and ditches excavations. When excavation soils are