Construction and Building Materials 53 (2014) 253–259

Contents lists available at ScienceDirect

Construction and Building Materials

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

Mechanical and durability properties of concretes containing recycled lime powder and recycled aggregates

Antonios Kanellopoulos [a,*], Demetrios Nicolaides [b], Michael F. Petrou [c]

[a] University of Cambridge, Department of Engineering, Trumpington Street, CB2 1PZ Cambridge, UK
[b] Frederick University Cyprus, Department of Civil Engineering, 7 Y. Frederickou Street, 1036 Nicosia, Cyprus
[c] University of Cyprus, Department of Civil and Environmental Engineering, PO BOX 20537, 1678 Nicosia, Cyprus

HIGHLIGHTS

- Recycled lime powder (RLP) does not seem to have any pozzolanic properties.
- RLP shows very good potential as a partial cement replacement material.
- Replacement of natural aggregates affects marginally the mechanical properties.
- We found good correlation exists between sorptivity and open porosity.

ARTICLE INFO

Article history:
Received 3 October 2013
Received in revised form 25 November 2013
Accepted 26 November 2013
Available online 22 December 2013

Keywords:
Concrete
Recycled waste
Recycled fillers
Recycled aggregates mechanical properties
Durability

ABSTRACT

According to a recent report by the European Commission, within the European Union, the construction and demolition wastes come to at least 450 million tons per year. Roughly 75% of the waste is disposed to landfill, despite its major recycling potential. The bulk constituents of demolition debris are concrete (50–55%) and masonry (30–40%) with only small percentages of other materials such as metals, glass and timber. In Cyprus, at present, recycling of waste materials is practically inexistent and almost the entire demolition waste products are disposed in landfill sites, with all possible economic, technical and environmental impacts. This research paper presents the evaluation and the effective reuse of waste construction materials, such as recycled lime powder (RLP) and recycled concrete aggregates (RCA), disposed to landfill sites in Cyprus, due to the lack of a lucid recycling policy and knowledge. Results show that both RLP and RCA have the potential to produce good quality and robust concrete mixtures both in terms of mechanical and durability performance.

1. Introduction

The conservation of earth's resources and sustaining the natural habitat has become the most crucial and serious problem for the continued existence and wellbeing of humankind. The natural sources of energy and materials have been consumed in great quantities by the rapid industrialisation and population growth over a span of more than two hundred years since the industrial revolution, resulting in global environment changes that humankind have never experienced. The problem we are facing today is that approximately 20% of the world's population, mostly living in Western Europe, North America and Japan, in order to maintain its standard of living consumes almost 80% of the world's resources and energy [1]. Meanwhile, the remaining 80% of global population has rapidly improved the rate of industrialisation in pursuit of a better life. One can easily understand that the result of this perpetual race for urbanisation encourages the continuation of consumption of natural resources at high rates. There are simply neither enough natural resources nor energy to continue our technological evolution as usual. It is imperative to find solutions that will assist to sustain the environment, without being an obstacle in the developmental race that meets the needs of not only the present but also future generations. The need for new infrastructure to support a minimum standard of life will increase as human population will continue growing, putting enormous demand on natural resources and the supply of construction materials.

It is widely accepted that concrete is the most versatile construction material in the world. It can be fabricated in all sorts of conceivable geometries, it has excellent mechanical and durability properties, its availability is widespread since its constituent materials are most readily available anywhere in the world; and more importantly its acquisition is relatively affordable especially compared to steel. This popularity of concrete is being translated into an annual worldwide production in the range of 12 billion tons, which accounts for about 1.7 billion tons of concrete per year per

* Corresponding author. Tel.: +44 1223 766683.
E-mail address: a.kan@eng.cam.ac.uk (A. Kanellopoulos).

0950-0618/$ - see front matter Crown Copyright © 2013 Published by Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.conbuildmat.2013.11.102

person living on this planet [2,3]. However, this popularity comes at price: concrete production has an enormous impact on the environment, a fact which at the past has been significantly overlooked. First of all the production of concrete requires vast amounts of natural resources each year. Then, the production of each ton of Portland cement releases almost one ton of carbon dioxide into the atmosphere. It is estimated that the cement industry alone is responsible for about 7% of worldwide CO_2 emissions, not to mention that the cement production is also very energy intensive. Third, the production of concrete requires large amounts of water, that fulfils certain standards, and water availability is a matter of concern these days. Lastly, the demolition and disposal of concrete structures creates another major environmental burden.

The building sector has a huge environmental impact and the EU job market depends heavily on the construction sector. Buildings and construction consume a lot of natural resources and generate a lot of waste. The sector uses more than 50% of all materials extracted from the earth and generates more than 450 million tonnes/year of waste in the EU according to a recent announcement by the European Commission [4]. Managing and disposing of old buildings is also problematic [5].

Within the European Union, the construction and demolition wastes come to at least 450 million tons per year. Roughly 75% of the waste is disposed to landfill, despite its major recycling potential. Some Member States (in particular Denmark, The Netherlands and Belgium) investigated thoroughly the technical and economic feasibility of recycling, achieving recycling rates of more than 80%. On the other hand, the South European countries recycle very little of their construction wastes [6]. The bulk constituents of demolition debris are concrete (50–55%) and masonry (30–40%) with only small percentages of other materials such as metals, glass and timber [7]. In the United States of America of the approximately 2.7 billion metric tons of aggregates used, about 70% are used in structural concrete, whereas about 30% is being utilised in pavements and road works [8,9]. Although, incentives for use of processed aggregates are given to promote use of RCA, though a large part of the production is suitable only as fill or construction base [8,9].

Several researchers studied the use of RCA to partially or globally replace natural aggregates in the production of concrete [10,11]. Density and water absorption ratio are the properties having the greatest differences in comparison with natural aggregates. These differences are mainly attributed to the lower density of the adhered mortar in the recycled aggregate, as reported by many authors [12,13] and have a negative impact on the concrete mixes. However, there are a few studies that prove that concrete made with coarse aggregates deriving from concrete recycling have mechanical properties similar to those of conventional concretes [14]. On the other hand, there is scepticism in the use of the fine fraction of these recycled aggregates. Not many studies have been conducted using fine fractions due to the belief that their greater water absorption can jeopardize the final results, particularly for replacement ratios exceeding 30% [15,16]. Moreover, recycled fine aggregates contain a larger amount of adhered mortar, which results in difficulties in procuring the required slumps, as well as a substantial increase in deformation, and sharp drops in the modulus of elasticity and strengths. Some researchers examined the effect of the addition of silica fume on the basic properties of recycled concrete (RC) [14]. However, very few projects have been able to provide conclusive evidence regarding the effect of mineral admixtures on the properties of recycled concrete. Finally, although a significant amount of work has been conducted regarding the mechanical behaviour of concretes made with RCA, very limited work can be found in the literature about their durability aspects [17–19]. The replacement of natural aggregates with recycled coarse aggregates increases dramatically the water demand. Therefore, dispersing agents have been used by several researchers.

Locally the recycling of construction wastes is a critical issue, considering that at the present time recycling of waste materials is practically inexistent and the fact that landfill sites are becoming increasingly difficult to come by, due to the small size of the island. This deficiency is getting sharper considering the confinement of the island due to the existing political issue. At the same time, resource supply or feed material can be guaranteed in Cyprus, where replacement of infrastructure is occurring, natural aggregate resources are very limited, and environmental regulations encourage recycling. This research work was considered imperative at national level, as it was aiming to enhance the state-of-the-art knowledge concerning the reuse of waste materials in construction industry and also boost the recycling process in Cyprus with all possible social, economic, technical and environmental benefits. The specific area lacks extensive international experimental data and is of primary interest in the case of Cyprus (arid climate, large CO_2 emissions in cities, and existence of reactive siliceous aggregates). Furthermore, the effect of the addition of a waste lime filler, deriving from the aggregates used in the production of asphalt concrete, on the properties of concrete was investigated.

2. Materials and mixtures

The experimental work was carried out in two stages. The first stage consisted of the evaluation as cement replacement material of a lime powder that comes as a by-product from the production of asphalt concrete. In the second stage of the work the production of robust concrete mixtures using two gradings of recycled aggregates, sourced locally, was investigated. A large number of mixtures were produced and tests were performed to determine their fresh, mechanical and durability properties.

2.1. Materials

2.1.1. Cement

To investigate the potential of recycled lime powder as cement replacement material, ordinary Portland cement CEM-I 32.5 was used. For the second part of the work, standard Portland pozzolan cement with a strength category of 42.5 N/mm^2 with sulphate resistance properties and low heat of hydration was used. All cements used in this study conform to the requirements of EN 197-1:2000 [20].

2.1.2. Natural aggregates

Graded crushed calcareous coarse aggregates in two different particle size gradings (8–20 mm and 4–10 mm) and two different gradings of calcareous sand (0–4 mm and 0–2 mm) were used. All natural aggregates were supplied by a local quarry.

2.1.3. Recycled concrete aggregates

The recycled aggregates were obtained from concrete rubbles available in Cyprus, using mobile impact crushers. It has to be mentioned that these rubbles represent a *best-case scenario* since they produced from leftover reinforced concrete laboratory specimens. Where necessary, material was refined in laboratory from a dry mill in order to allow the maximum grain sizes required for concrete mixes. Two fractions of recycled coarse aggregates were used in this work, namely 4–10 mm and 8–20 mm. The remaining fractions (<4 mm and > 20 mm) were rejected, by applying sieving operation. Note that for the production of all concrete mixtures the same particle size ranges for both natural and recycled aggregates were used. Both types of aggregates were tested regarding their grading, flakiness index, abrasion resistance, density and water absorption [21–24].

Table 1 summarises the properties of both natural and recycled aggregates used in this study. It is noticeable that the abrasion resistance of recycled aggregates, as this derived from the Los Angeles test, is comparable to the corresponding value for natural aggregates. This was attributed mainly to the poor quality of natural aggregates available on the island, which have water absorptions in the range of 2.7–4%. In addition, the water absorption of recycled materials was well higher than the corresponding values for natural aggregates, due to the existence of the hardened cement paste covering the surfaces of recycled materials.

2.1.4. Recycled lime powder

The recycled lime powder (RLP) used in this study is a waste material of the asphalt concrete production process. Calcareous aggregates used in this process are being heated at 800 °C in special kilns, then the surface dust is blown away