Construction and Building Materials 47 (2013) 1–6

Contents lists available at SciVerse ScienceDirect

Construction and Building Materials

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

Strength performance comparison of mortars made with waste fine aggregate and ceramic fume

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ARTICLE INFO

Article history:
Received 9 February 2013
Received in revised form 19 April 2013
Accepted 30 April 2013
Available online 22 May 2013

Keywords:
Mortar
Fine aggregate
Ceramic waste
Cement replacement
Composite
Non-structural concrete
Ceramic fume

ABSTRACT

This paper presents results of the research programme focused on utilising multiple waste materials in production of cement mortars. Waste sand of natural origin was harnessed as aggregate. Ceramic waste fume obtained as a by-product during manufacturing of coarse "post demolition" aggregate was used to partially replace binder in mortar mixtures. Properties of both fresh mixes and hardened mortars were tested and analysed. Such properties as: consistency of fresh mix, density, compressive strength and flexural strength of hardened composites prove that mortars in question can be used to fabricate elements characterized by less demanding mechanical characteristics.

1. Introduction

Concrete, mortar and other cement composites are the most common construction materials in the world. Aggregate covers from 60% to 80% of cement composite volume. Global annual production of concrete, mortar and other cement composites consumes 20 billion tonne of different aggregate [13]. It means that about 3 tonne of aggregate is used per person per year, which considerably influences natural environment [16]. In many areas, the growing difficulty in obtaining natural coarse aggregates for the production of cement composites (usually ordinary concrete) led cement composite manufacturers to search for feasible alternatives [5,17]. The first way to solve this problem is to create cement composites based entirely on fine aggregates. There are vast areas of the world with excessive resources of natural fine aggregate and numerous research attempts to harness this kind of aggregate as main (or only) aggregate in cement composites were quite successful [1,4,11,24]. The second way to solve the problem is to use construction and demolition waste as aggregate [22]. The most ecologically efficient and sustainable solution would be combining both approaches and creating a cement composite based on two types of aggregate: fine and demolition waste. Such an approach would address multiple ecological and technological issues associated with disposing the waste, recycling of construction and demolition waste and conserving available resources of natural aggregate. This article presents the results of an experimental programme where the technological viability of creating fine aggregate cement composite based entirely on waste fine aggregate of natural and demolition origin was examined. There were harnessed two types of waste aggregates: waste sand of natural origin thoroughly described in numerous previous publications [8–10] and ceramic fume obtained as a by-product during manufacturing of coarse "post demolition" aggregate. The author decided to test mortars in question using ordinary procedures described by European codes and standards. This approach would enable to compare the performance of tested non-conventional composites with traditional mortars (utilized by construction industry on mass scale on daily basis). The main aim of the research programme was to prove technical and practical civil engineering serviceability of tested mortars and assess the replacement potential of ordinary mortars.

2. Harnessed materials, mixing and curing procedures

Building rubble from the demolition of degraded buildings keeps on growing in Europe. The amount of construction and demolition waste produced only in 15 European countries is about 180 million tonnes per year with an increasing trend [5]. Although the reutilization of ceramic debris has been practiced, the amount of waste reused this way is still negligible and in majority of cases incorporates only coarse fractions. Fine fractions of ceramic waste aggregate obtained during crushing ceramic debris is still not

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http://dx.doi.org/10.1016/j.conbuildmat.2013.04.039

Table 1
Grading characteristic of the ceramic fume.

Sieve (mm)	0.063	0.125	0.200	0.250	0.300	0.385	0.430	0.500	0.600	1.000	2.000	4.000	8.000
PP (%)	29.6	44.9	49.7	58.5	69.7	71.8	75.6	86.2	98.2	98.7	98.9	99.7	100.0

Fig. 1. Waste sand – a by-product of hydroclassification process of all-in-aggregate (photo by J. Katzer).

exploited although several researchers confirmed the puzzolanic reactivity of ceramic powder [12,14,23]. On the other hand the production of cement is an energy intensive process and requires 3.57GJ per 1 tonne of clinker [13]. It also implies the extraction of large quantities of raw materials from earth (1.7 tonnes of rock to produce 1 tonne of clinker) [13,15]. The production of one tonne of cement generates around 1 tonne of CO_2, which means that global cement production accounts for about 7% of the total carbon emissions [13]. Therefore, the replacement of cement in concrete by ceramic waste powder would represent a tremendous saving of energy and has important environmental benefits.

For the purposes of the research programme a ceramic fume obtained as a by-product during manufacturing of coarse "post demolition" aggregate was used. Grading characteristic of this fume is presented in Table 1. This fume was used to partially replace binder (Portland cement CEM II/B-V 42.5N – conformable PN-EN 197-1:2002 [18]) in mortar mixtures. Waste post-glacial sand of hydroclassification origin (Fig. 1.) was utilized as aggregate. This sand and its applications in different cement composites were described in numerous previous publications [6,8,10]. Tap water (PN-EN 1008:2004 [19]) constituted the last component of the mix.

A standard mortar mix composition, used to prepare specimens for testing compressive strength of cement [20], was set as a preliminary mix. The proportions of materials for one cubic meter of the standard mortar mix are as follows: cement = 512 kg, water = 256 kg, sand = 1534 kg. The mix was modified by admixture of 1% of highly effective superlasticizer (Betocrete-406 FM). All mortars were prepared with the help of a standard mortar mixer and standard mixing procedure (firstly slow speed mixing – 140 rpm for 30 s, then high speed mixing – 285 rpm). There were cast nine prism specimens (40 mm 40 mm 160 mm) out of each batch. The first step of curing was to keep the specimens in their moulds covered with polyethylene sheets for 24 h. The specimens were then removed from their moulds and cured by storing them in a water tank (Temp: +21 °C). The mixing/casting sequence and curing procedure of discussed mortars was described in detail in a previous publication [7].

3. Research programme

The programme of experiments was divided into two main stages. The objective of the first stage was to determine the workability of fresh mortars and density of hardened mortars. The second stage was to conduct compressive (f_c) and flexural (f_f) strength tests. The compressive test was conducted on the surface of 40 mm 40 mm = 1600 mm^2. The flexural test was conducted on freely supported prisms (span 100 mm) and loaded in the middle by single force. There were tested three groups of mortars characterized by *w/c* ratio equal to 0.50, 0.55 and 0.60 respectively. In each group of mortars the amount of cement which was exchanged by ceramic fume varied from 10% to 50% (by volume). Mix composition and properties of the three introductory mortars with no ceramic fume are presented in Table 2.

The examination results were statistically processed, and values bearing the gross error were assessed on the basis of Grabbs criterion [2]. The objectivity of the experiments was assured by the choice of the sequence of the realization of specific experiments from a table of random numbers. All mathematical relations were established to get the best fitting correlation with the help of simplest function. In case of density and flexural strength simple linear relation gave the best fitting correlations for all analysed *w/c* ratios. Compressive strength results needed employment of cubic functions to get satisfactory fitting correlations. All charts were plotted with prediction intervals (probability 95%).

4. Results and discussion

All achieved results were presented with the help of bubble charts which display three dimensions of data. Bubble charts can be considered a variation of the scatter plot, and plotted when considered data has at least three data series, each of which contains a set of values. The data points are basically replaced with bubbles. The entities displayed on a bubble chart can be compared in terms of their size as well as their relative positions with respect to each numeric axis. In the discussed research programme horizontal axis represents the volume of cement exchanged by ceramic fume and vertical axis represents tested physical or mechanical property (e.g. density or strength). The position of the plot is an indicator of those two distinct numeric values and the area of the plot depends on the magnitude of the third numeric characteristic which in this

Table 2
Mortar composition and properties.

w/c	Cement (kg)	Water (kg)	Aggregate (kg)	Admixture (kg)	*d* (mm)	ρ (kg/m$^{3)}$	f_c (MPa)	f_f (MPa)
0.50	0.450	0.225	1.350	0.005	165	2207	27.9	6.9
0.55	0.450	0.247	1.314	0.005	185	2210	24.4	6.2
0.60	0.450	0.270	1.278	0.005	200	2250	16.7	5.6