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ORIGINAL ARTICLE

Utilization of crushed clay brick in cellular concrete production

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Abstract The main objective of this research program is to study the effect of using crushed clay brick as an alternative aggregate in aerated concrete. Two series of mixtures were designed to investigate the physico-mechanical properties and micro-structural analysis of autoclave aerated concrete and foamed concrete, respectively. In each series, natural sand was replaced with crushed clay brick aggregate. In both series results showed a significant reduction in unit weight, thermal conductivity and sound attenuation coefficient while porosity has increased. Improvement on compressive strength of autoclave aerated concrete was observed at a percentage of 25% and 50% replacement, while in foamed concrete compressive strength gradually decreased by increasing crushed clay brick aggregate content. A comparatively uniform distribution of pore in case of foamed concrete with natural sand was observed by scanning electron microscope, while the pores were connected mostly and irregularly for mixes containing a percentage higher than 25% clay brick aggregate.

1. Introduction

Crushed clay brick is not considered a recyclable material in the Middle East as opposed to recycled concrete aggregates which a few Arab countries began to produce for non-structural purposes. The first use of crushed brick with Portland cement was recorded in Germany (1860) for the manufacturing of concrete products, but the first significant use of crushed brick as aggregates in new concrete has been recorded for reconstruction after the World War II [1]. A number of researches have been reported to evaluate the potential of using crushed clay bricks as an alternative aggregate. Most current researches use crushed clay brick as a coarse and/or fine aggregate in normal conventional concrete. Few researches reported that crushed brick powder, CBP, could be used as partial replacement of cement in concrete. Moriconi et al and Turanli et al [2,3] classified CBP as a pozzolanic material. Recycling crushed clay brick wastes needs more researches to make the maximum use of these wastes. Producing aerated concrete with crushed clay brick as an alternative aggregate will present solution for these recyclable wastes. The preparation of aerated concrete by incorporation of pozzolanic siliceous material received further attention because of the economical use of

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naturally occurring raw materials, waste material recycling and saved energy [4].

Nowadays aerated concrete is widely used because of its unique characteristics. It possesses high flowability, low self-weight, controlled low strength, excellent thermal insulation properties and fire resistance. Classification of aerated concrete based on the method of pore-formation can be summarized as air-entraining method (gas concrete), foaming method (foamed concrete) and combined method [4].

The first type of aerated concrete is autoclave aerated concrete (AAC) which is classified as a gas concrete produced by cement and lime as calcareous materials, and by quartz sand as the siliceous materials with traces of aluminum powder as a pore forming agent. After mixing these components with water, aluminum powder reacts with calcium hydroxide which liberates hydrogen gas and forms bubbles that lead to a porous structure concrete. Autoclave curing is a heat treatment which has been used to accelerate the strength development of concrete products. Because the hydration rate of cement increases with the temperature increase, the gain of strength can be speeded up by curing concrete in steam [5]. Several researchers have investigated the possibility of replacing the traditional raw materials of autoclave aerated concrete by industrial waste, such as coal bottom ash [5], natural zeolite [6], air-cooled slag [7], lead zinc tailings [8], iron ore tailings [9] and sand–phosphorus slag–lime [10].

The second type of aerated concrete is foamed concrete, FC, which has not involved chemical reactions. Introduction of pores is achieved through mechanical means either by pre-formed foaming (foaming agent mixed with a part of mixing water) or by mix foaming (foaming agent mixed with the mortar). A lot of studies have explored the use of alternative pozzolanic and/or siliceous materials in foamed concrete production. Fly ash and ground granulated blast furnace slag have been used in the range of 30–70% and 10–50%, respectively as cement replacement. Also, fly ash, lime, chalk, crushed concrete and recycled glass were used as alternative fine aggregates. All of these researches aimed to reduce the density of foamed concrete and/or to use waste recycled materials [11].

2. Research significance and scope

The major objective of this study is the utilization of clay brick aggregate and powder in producing cellular concrete. This study mainly focuses on exploring new suitable alternative siliceous materials for cellular concrete production. In this study, fine crushed clay brick aggregate is used as raw materials to prepare cellular concrete. It is considered as an alternative siliceous resource to reduce the consumption of sand and it is also expected to enhance mechanical properties for both autoclave aerated concrete and foamed concrete because of its recorded pozzolanic reactivity.

3. Experimental research program

3.1. Materials

Crushed clay brick wastes were manually crushed using a steel hammer, then screened and grouped to different sizes in accordance with ASTM C33 to comply sizes presented in Table 1. This grading was used for foamed concrete preparation.

Table 1 The properties of the used aggregates in foamed concrete FC.

Properties	Natural aggregate	Recycled aggregate	Limits
Specific gravity	2.710	2.430	–
Fineness modulus	2.32	2.44	–
Absorption (%)	0.90	20.0	–
Particle size distribution (mm)	Percent passing		< 3/16″
4.75 (No. 4)	100	100	95–100
2.36 (No. 8)	100	100	80–100
1.18 (No. 16)	81	74	50–85
600 μm (No. 30)	55	52	25–60
300 μm (No. 50)	30	24	5–30
150 μm (No. 100)	2	6	0–10

Additionally, the crushing process produces smaller aggregates. This dust-clay brick powder, CBP, was separated by 75 μm mesh sieve. Clay brick powder was used as an alternate aggregate in autoclave aerated concrete mixture preparation.

Evaluation of the particles shape showed CBP grains to be a semi-oval shape and a semi-smooth surface. Fig. 1 shows the particle shape of clay brick powder grain shape.

Portland cement CEM I 42.5 N, lime with 83.9% CaO, natural sand and crushed clay brick with particle size up to 75 μm, aluminum powder with percentage of 94.2% of purity as a gas generating agent and potable water were used for producing autoclave aerated concrete, AAC. Physical, mechanical and chemical properties of cement and clay brick powder are given in Tables 2 and 3.

The used materials for foamed concrete, **FC**, were the same ordinary Portland cement CEM I 42.5 N used in AAC and natural siliceous sand with fineness modulus of 2.34. Clay brick aggregate was obtained by manual crushing as previously mentioned and Table 1 shows the physical properties and grading of either sand or fine crushed clay brick aggregate used in foamed concrete. The used doses of Type F chemical admixture for concrete mixes are 2.25% by weight of cement. Synthetic foaming agent has been used as a foaming agent during this section.

3.2. Mix proportions and sample preparation

3.2.1. Autoclave aerated concrete

Firstly, five different types of autoclave aerated concrete, **AAC**, were prepared by progressive incorporation of clay brick powder, CBP. Autoclave aerated concrete is always produced in a specialized factories. In these factories, the measure of the used materials is conducted by weight not by volume. Thus, in autoclave aerated concrete samples' preparation, the replacement by weight was respected as followed by earlier studies and practical applications. The replacement levels were 0%, 25%, 50%, 75% and 100%. Cement:fine aggregate:lime ratio (C:F:L) was chosen as 1:3:0.2 by weight. This ratio was chosen based on trials. The water to solid ratio was 0.6. Aluminum powder was added at 1.0% by weight of solid. Although previous researches used lower doses of aluminum powder, trial mixes in this research program showed that 1.0% aluminum