USABILITY OF THE TURKISH COAL BOTTOM ASH AND NATURAL ZEOLITE IN CONCRETE APPLICATIONS

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Abstract

The usage of binders or pozzolanic materials in the production of concrete is not new. However, in recent years, the use of the pozzolanic siliceous material such as natural zeolite and coal combustion ash (CBA) has received re-attention due to the generated considerable interest in the economical use of both naturally occurring raw materials, recycling of the waste material and saved energy.

In this study, the potential and utilization opportunities of natural zeolites and bottom ash (BA) in concrete applications were reviewed. Case studies, conducted to determine the possible usage of the natural zeolite and BA in concrete production, i.e. light weight concrete (LWC) were also presented. The physical and mechanical properties of cured concretes were examined to find out the competitive material usage on the final product properties.

Introduction

Autoclaved aerated concrete (AAC) with 1.1 nm tobermorite ($5CaO\ 6SiO_2\ 5H_2O$) as binder is a lightweight construction material that mainly uses in place of concrete to manufacture various building materials, including blocks, panels, slabs and the like. The material is a mixture of sand, lime, cement, gypsum, water and an expanding agent, which causes the raw material to rise like bread dough, with countless small air pores. AAC can be molded and cut into precisely dimensioned units and cured in an autoclave, which steam cures the concrete under pressure. During this process, the ingredients combine to form the calcium silicate hydrate gels that establish the special properties of the finished product. The process produces a material that is only one-fourth to one-third the weight of a conventional concrete block (bulk density of 400-800 kg /m^3) of the same size. Regular AAC offers considerable advantages over other construction materials such as high thermal and sound insulation, excellent fire resistance, high resource and energy efficiency, low environmental impact, and finally outstanding structural performance (especially for earthquake zones) [1]. Its lightweight also makes it easy to use during construction, and its aerated structure gives it better thermal insulation and sound absorption properties than conventional concrete

AAC products were first developed in Europe in the early 1920's as an alternative building material to lumber. A Swedish architect, Axel Johanson, introduced the product to Europe. Since that time, AAC has become widely used in building construction around the world. Like other countries such as U.S, Chine, India and EU, in last decades, the share of the AAC in the total domestic concrete market has also progressively increased in Turkey. In 2004, the total amount of consumption was reported as 1.4 million m^3, which made the Turkey 4th biggest AAC producer in the EU.

Undoubtedly, the occurrence of the 1.1 nm tobermorite is the most important feature of the AAC production. The phase evolution during the production of AAC was reported at early study performed by Mitsuda.et al [2]. It was suggested that alite and belite in cement were mainly transformed to the C-S-H phases and $Ca(OH)_2$ during molding process. With an application of autoclaving process, the initial products occurred due to hydrothermal reactions between the various components in green body: $Ca(OH)_2$ –quartz, cement –quartz and C-S-H-quartz. At this stage, hydrothermally formed C-S-H rapidly reacts with dissolves silica and decreased the Ca/(Al+Si) near 1.0. Than after, well crystalline tobermorite phase is occurred with proceeding of the autoclaving time. The composition of C-S-H and tobermorite as a binder continuously change until after 8 h, when the ratio Ca/(Al+Si) becomes constant at 0.8. It was concluded that hydrothermal reactions in the CaO-quartz system are controlled by the dissolution of quartz, and this reaction determines the AAC processing time.

A number research studies [3-5], performed to find out the micro structural variations of AAC during the production were also supported these transition stages. The material structure of AAC is characterized by its solid microporous matrix and macropores. The macropores, which were generated by hydrogen (Figure 1-a) generally envisaged a diameter of more than 60 μm. The macropores shape and size remained unchanged before and after autoclaving while the micropore distributions were very sensitive to the products formed by hydrothermal reaction At the early stage of the curing, however, the C-S-H phases were generally envisaged as fibrous aggregates, with prolonged the curing time, these crystallized as lathlike thin plates of tobermorite by the rapid reaction of dissolved silica (Figure 1-b) .With the occurrence of the crystalline 1.1 nm tobermorite, the size of the micropores shifted from 6 μm to 50 nm–100 nm.

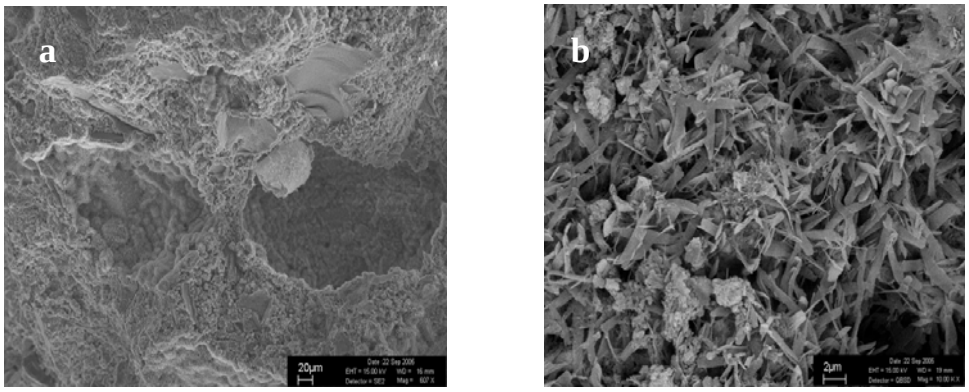


Figure 1. Microstructure of AAC: (a) macropores and (b) tobermorite gels

In recent years, the preparation of lightweight concrete by incorporation of pozzolanic competitive siliceous material such as silica fume, coal fly ash, slugs and natural zeolite has received further attention due to the generated considerable interests in the sustainable and economical use of natural recourses, stringent environmental directives to recycle of the waste material, and saved energy [6]. Coal ash generated from power plants have become an important economic and environmental objective, and thus calls for recycling alternatives to traditional landfill option due to the their high generation amount and low recycling rate. Although large amount of coal fly ash has already been utilized in the construction industry as a partial cement replacement and/or mineral additive in concrete production, the usage of CBA is limited due to its relatively higher unburned carbon content and different structural properties compared to fly ash. The utilization potential of fly ash is mainly controlled by its chemical composition, whereas the utilization potential of BA is determined more by its physical characteristics such as grain-size distribution, soundness, staining potential, and color. The normally coarse, fused, glassy texture of BA makes it an ideal substitute for natural aggregates [7]. Nevertheless, it is often used as a low-cost replacement material in many countries such as base in road construction. For that reason, in recent years in the

United States and in many other countries throughout the world, there has been an increased effort to reduce the amount of waste discarded in landfills, by either reducing the amount of waste products produced or by converting waste products into useful materials, or by doing both. In literature, a large number of significant results have been reported on the use of fly ash in concrete however, there is not much literature available on the use of fly/bottom ash as partial replacement of fine aggregates or Portland cement for the production of AAC. Nisnevic [8] investigated the effect of fly ash volume on the porosity and strength of light weight concrete made with Portland cement, fly ash and course and fine aggregates of BA. It was reported that AAC with decreased cement fly ash paste porosity and increased concrete strength could be made. The effect of fly ash, BA and Lytag usage as replacement material in place of ordinary Portland cement, natural sand and coarse aggregate, on the properties of AAC was studied by Bai et al [9]. The results indicated that it is possible to manufacture lightweight concrete with density in the range of 1560-1960 kg/m^3 and 28-day compressive strength in the range of 20-40 N/mm^2 with various waste materials from thermal power plants. Although commercially available lightweight fine aggregate has been used in experiments in place of natural sand to manufacture of lightweight concrete, more environmental and economical benefits can be achieved if waste materials can be used to replace the fine lightweight aggregate. The WO patent titled "Method of manufacturing autoclaved, cellular concrete products using bottom ash" disclosed that a saleable product could be obtained with using finely ground bottom ash (about 70% by weight) which is mixed with water, lime (about 16% by weight) and cement (about 13% by weight), and about 4% by weight of other ingredients which act as binders and reaction carriers, such as aluminum power, siloxane and anhydrite [10]. It was suggested that fly ash, which is another by-product of the coal burning process, may be used to form AAC products. However, bottom ash has unexpected advantages over fly ash in the production of AAC products. In particular, BA is composed of particles that tend to be too large to become airborne, and therefore the transport of BA is much easier and less hazardous than the much smaller fly ash. Rather than the coal combustion ashes a natural zeolite especially clinoptilolite has also received attention for he production of AAC. Numerous reports[11-14] are reported that natural zeolite, mainly clinoptilolite can beneficially be used as a binder, aggregates or air foaming substance in a mixture formulation with different replacement amounts. However, it should be concerned that, the physico-chemical properties of raw materials, mixture formulation and employed methods are significantly affected the final properties of concrete.

Case Study

In Turkey, nearly 28% of the total primary energy is supplied from the burning of lignite coal. The ashes produced annually from 11 power plants vary from 6.5 to 13 M tonnes. However, in recent years the re-utilization of these wastes has increased considerably, it is still far from the required recycling rate. On the other hand Turkey has 50 billon tons of natural zeolite, mainly clinoptilolite reserve. Only 40.000 tons of this reserve was mined and consumed in 2005 mainly as a soil conditioner and feed additives. The purpose of this study is to find out the possible usage of BA and Turkish natural zeolite; clinoptilolite (CLN) in AAC production. The received BA was first pretreated by crushing and particle size classification method to decrease its higher unburned carbon to desirable level or that generally accepted by concrete industry (< 6%). The pretreated ash and CLN were then used as an aggregate with different replacement amounts.

Materials and Method

The BA used in this study was obtained from Tunçbilek Thermal Power Station, located in central Turkey. The station consumes about 2.350.000 tons of low-grade lignite coal (calorific value varying from 2250 to 3900 kcal/kg) and generates 854.670 ton ash annually. According to chemical composition, 60% SiO_2; 16.65% Al_2O_3; 9.95% Fe_2O_3, the BA sample

could be classified as a type F ash as prescribed by ASTM C 618. The zeolite sample, supplied from Manisa Gördes, was crushed; grinded and classified in to 0.5 - 1 mm before utilizing in AAC mixtures. According to XRD analysis it was found that CLN sample mainly consists of clinoptilolite, quartz and feldspar phases. Representative AAC compositions were prepared by progressive incorporation of zeolite or BA in place of quartz sand (0, 25, 50, 75 and 100 wt-%) in to the concrete mixture. Solid materials were mixed together for 1 min. The solid mixture was than mixed with water at w/s ratio between 0.6-0.75 and 0.2-0.275 for BA and zeolite respectively in mixer for 2 min, with addition of 0.5% aluminum powder. After molding, the specimens were first cured in furnace at 40˚C for 3 hrs to achieve the desired setting and volume stability and then autoclave curing was conducted under 12 atm at 180-200˚C steam pressure for 18 hrs. The compressive and flexural strength tests were performed with ELE Autotest 3000 testing machine on 70×70×70 mm and 40×40×160 mm bottom ash aerated concrete (BAC) specimens, respectively, as defined in TS 453 and TS EN 771-4. Thermal conductivity measurements were carried out in accordance with ASTM C 1113-99 Hot Wire method (Anon, 2004) using Kyoto Electronics QTM 500 quick thermal conductivity meter on dry samples.

Results

Mechanical Properties

The variation of the flexural strengths of BAC and ZAC specimens versus BA or CLN replacement ratio are presented in Fig. 2. A gradual flexural strength increase was obtained with increasing replacement ratio of BA and CLN up to 50% for 18 hrs autoclave curing.

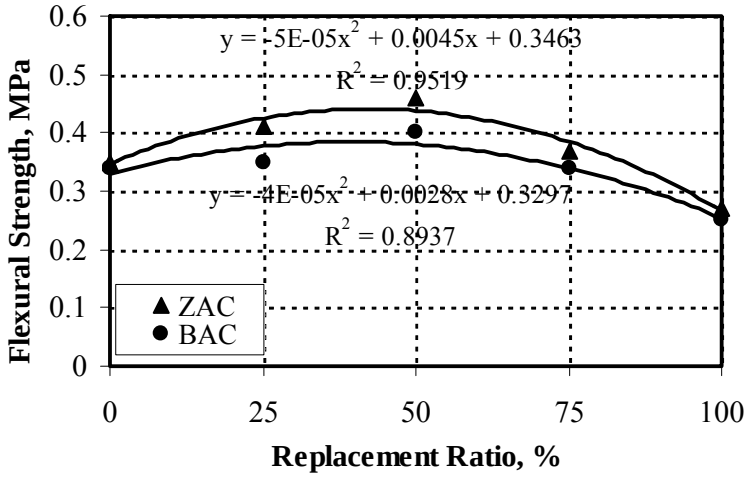


Figure 2. Flexural strength of ZAC and BAC specimens

The flexural strength increase of ZAC-25 and ZAC-50 was determined as 17% and 32% respectively. On the other hand, the flexural strengths of BAC-25 and BAC-50 were 3% and 16% higher than reference sample (RS) respectively. Further increases in the BA addition decreased the flexural strength of the BAC and ZAC specimens. This decrease is also related with the increasing w/s ratio of both AAC mixtures.

The variation of the compressive strengths of BAC and ZAC specimens versus BA and CLN replacement ratio are presented in Fig. 3. The compressive strength of the BAC increased from 2.54 MPa to 2.78 MPa compared with that of RS. On the other hand, a relatively higher strength values determined for ZAC clearly indicating the effect of zeolite addition on the strength development of lightweight concrete. The flexural and compressive strength of concrete increased from 17 % to 32 % and 16% to 28 % for Z-AC-25 and Z-AC-50

respectively. The strength increases compared to reference sample could also be attributed the pozzolanic reaction between zeolite and $Ca(OH)_2$.

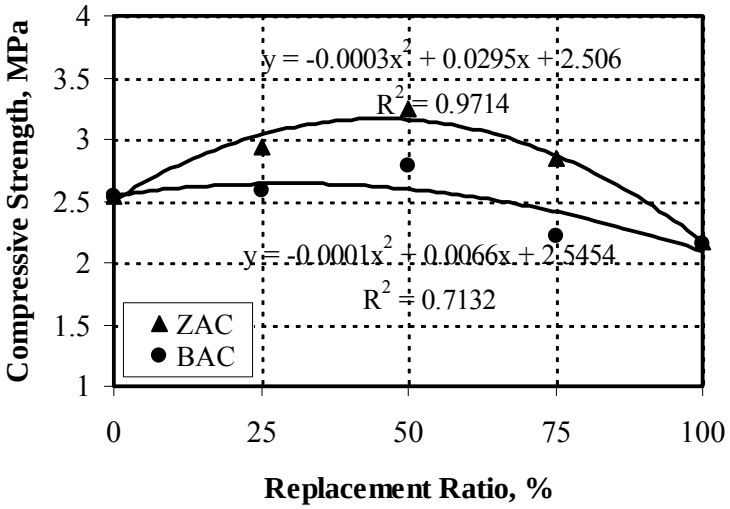


Figure 3. Compressive and flexural strength of Z-AC specimens

Thermal Conductivities

A comparison of the measured thermal conductivities of BAC and ZAC specimens cured for 18 hrs were given at Figure 4. For both type of concrete thermal conductivity values reduced with increasing replacement ratios. Although the lowest conductivity value was obtained for the BAC sample at 100% BA replacement amount, the decreased strength values of this concrete limited the usability. The obtained conductivity for the specimen having 50% BA and 0.2826 W/mK was relatively higher than the commercial AAC produced in Turkey, 0.2443 W/mK; however, it can be acceptable for the general classification reported for the AAC [1]. A same relation with lower conductivity values was also determined for ZAC specimens. A lower specific gravity and higher energy absorption capacity of zeolite lead to the decrease in the heat transfer and thermal conductivity of ZAC. According to thermal conductivity test results, ZAC and BAC blocks can be use in structures as thermal insulation walls and panels.

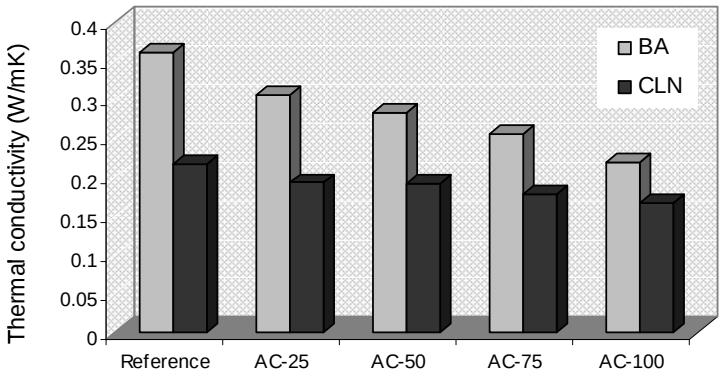


Figure 4. Thermal conductivities of BAC and ZAC specimens

Conclusions

The modern use of pozzolans as a cement replacing or enhancing admixture in concrete began many decades ago. This is not new or an "alternative" in the construction industry, but a trend toward greater usage and is now redefining acceptable practice. Often restricted by building codes to small fractions of the cementitious material in a concrete mix, pozzolans

have held a relatively minor role in the concrete industry. But the trends in using mineral additives in concrete mixture are now active and would change that minor role to a major one for sustainable development. According to test results it can be clearly seen that the CLN and BA replacement have beneficial effects on final AAC properties. The mechanical and physical test results of BAC and ZAC specimens leads to use these waste materials as a supplementary material in AAC production.

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