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Review

Previous and present investigations on the components, microstructure and main properties of autoclaved aerated concrete – A review

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HIGHLIGHTS

- AAC is widely used due to its excellent thermal insulation property and easy availability.
- Components, microstructure and main properties of AAC were comprehensively and thoroughly reviewed.
- Future research suggestions were presented based on the overview.

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ABSTRACT

Autoclaved aerated concrete (AAC) has being attracted more and more attention as its excellent thermal insulation and environmentally friendly characteristics. The properties of AAC depend on components, microstructure and external environment (e.g. relative humidity and CO_2). Previous investigations systematically demonstrate the evolution of microstructure and variation of physical properties with different kinds of binders and curing conditions, while present researches enhance the understanding of interaction among comprehensive factors. This paper mainly refines the literatures on AAC in terms of constituent materials (especially industrial wastes and additives), preparation, microstructure and main properties (density, dry shrinkage, hygric property, mechanical properties, anisotropy, thermal insulation and durability). Based on the review, urgent needs should be made in efforts as follows: (i) compatibility between the stiffness rate of AAC slurry and the gas-generation rate; (ii) relationship between the connectivity of pores and thermal insulation; (iii) measures to better the durability.

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1. Introduction

By virtue of thermal and sound insulation, excellent fire resistance, high resource and energy efficiency and outstanding structural performance [1], AAC has been used in the non-structural and structural construction since the mid-1920 s [2]. Compared with normal concrete and bricks, AAC reduces 70% and 40% energy per volume of material [3], thus is considered to be environmentally friendly material. AAC is normally produced though molding and hydrothermal process of various raw materials mainly including sand, lime, cement, water and expanding agent (the most common is aluminum powder) [1,3]. In the molding process, all raw materials are forced to mix uniformly accompanied by expanding to above twice volume of the initial mixture, resulting in a highly cellular structure. During the hydrothermal process, the green body of AAC is strengthened by autoclaving under steam pressure, in which the 1.1-nm tobermorite and well-crystallized C-S-H are formed as the main binding phases [4]. In 2000, Narayanan and Ramamurthy [5] systematically reviewed the investigations on the production and properties of AAC, and a comprehensive and in-depth work was accomplished in 2009 by Ramamurthy et al. [6] who summarized constituent materials, mix proportion, production methods, fresh and hardened properties of the foamed concrete (a superior concept of AAC). Although AAC is usually regarded as traditional material, and massive research achievements have been published, there is plenty of room for improvements in the optimization of composition, shrinkage, thermal property and long-term durability. The final properties depend on many factors, e.g. nature of raw materials, proportioning design, autoclaving conditions, and impacts of these factors always vary with the development of materials and equipments as well as our deeper understanding. In the view of update, this paper mainly focuses on recent investigations on constituent materials, microstructure and main properties of AAC.

2. Constituent materials

AAC is classified into two series: cement or lime based depending on different calcareous materials used or sand and fly ash based according to different siliceous materials used. Aluminium powder is the most common air-entraining agent to introduce a void-trapped system. Recently, using industrial by-products for preparing AAC has gained extensive attention owing to the stringent environmental directives to recycle waste. In addition, some waste, such as municipal solid waste incineration bottom ash can replace conventional aluminum powder to act as aerating agent and active silicon source [7].

2.1. Industrial by-products used as substitution materials

Supplementary cementitious materials such as slag, fly ash and silica fume have been increasingly used in the preparation of AAC. Addition of coal bottom ash and silica fume increases the density and decreases the volume of permeable voids due to the reduction in hydrogen gas, while excessive addition of coal bottom ash (more than 30%) can weaken the strength. Besides, silica fume is beneficial for the strength due to its higher pozzolanic activity than ash, but variations of ash and silica fume have slight effect on the thermal conductivity of AAC [8,9]. Replacement of rich husk ash to sand has the advantage of reducing curing time or curing temperature by investigating on the variations of compressive strength and formation of tobermorite [10]. Table 1 presents an overview of the application of industrial by-products into the production of AAC.

2.2. Application of additives

2.2.1. Fibers

AAC is inherently brittle by nature, based on the similarities of fiber-reinforced aerated concrete (FRAC) to AAC [3], fibers are considered to increase the ductility of AAC due to bridging the micro and macro cracks. Comparisons of the mechanical behaviors of AAC and FRAC under compression and tensile/flexural stress are shown in Fig. 1. It is illustrated that the ratio of residual strength to peak strength for FRAC is typically more than AAC, and under tensile/flexural stress AAC breaks once the ultimate strength is reached, but FRAC shows a ductile response. Compared with AAC, the compressive strength, modulus of elasticity, and toughness (at 1.3% strain) of FRAC with density of approximate 600 kg/m^3 and 0.2% polypropylene fibers (average length of 12 mm, aspect ratio of 250) decrease by 43%, 40% and 18.4%, respectively, however, the residual strength increases by 12.5%. Surprisingly, the flexural toughness of FRAC is 83 times more than that of AAC in the three-point bending tests. It should be noted that FRAC has considerably lower compressive strength due to the elimination of autoclaving process in order to avoid any damage to the polypropylene fibers [3]. High volume fly ash (60%) in FRAC contributes to very low pozzolanic reaction rate at room temperature.

The type, geometry, dimension and dosage of fibers decide their effects on the mechanical properties of AAC. Laukaitis et al. [29] confirmed that the capacity of increase in the compressive and flexural strength followed in the order: carbon fiber > polypropene fiber > basalt fiber > kaoline fiber. Technical parameters of these fibers and strength results are listed in Table 2. The differences of reinforcement effect from fibers depend on their chemical