Effect of rubber powder on autoclaved aerated concrete properties

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Abstract

Disposal of waste tires in nature is one of the significant environmental problems. Autoclaved Aerated Concrete is a lightweight or porous gaseous concrete. The use of crumbed rubber in autoclaved aerated concrete improves the mechanical properties of bricks and saves energy. On the other hand, because of the reduction in natural raw materials, concrete composite with rubber particles is both economically and environmentally friendly. In this study, autoclaved aerated concrete was produced in the presence of diffrent crumb tire particle size. The results showed that the presence of crumbed rubber changes density increases the plastic behavior of concrete and, increases the sound absorption ability. Reducing the size of rubber particles increases the sound absorption.

Keywords: Autoclaved Aerated Concrete (AAC), Recycling Waste Tires, Crumb Rubber, Absorption Coefficient, Energy Saving.

Introduction

The issue of waste tires is a major environmental problem. Waste tires released in nature are seriously threatening the environment [1]. Rubber Disposal Waste rubber is used in a variety of ways, such as burning [2] and landfilling [3], as mulching on the sports field and asphalt bond modifier [4]. Stored waste tires cause health, environmental and, economic hazards through air, water and, soil pollution [2]. Approximately 1.5 billion tires are manufactured around the world annually, out of which 1,000 million tires annually complete their service life, and it is projected to reach 1200 million tires in 2030 [2]. Due to the uniqe shape and impermeability of the structure, tires hold water for a long time, which is a habitat for many mosquitoes and pests [2]. When the tire is set on fire, temperatures rise and, toxic fumes disperse without any control over their release, containing harmful and hazardous compounds to humans, animals and, plants. Tires are usually made from chemical ingredients such as styrene and butadiene that burn styrene to various benzene compounds and burn butadiene due to having four carbon atoms in a highly carcinogenic structure and impede air pollution and black surfaces by emitting black smoke. Dirty. Gases from combustion rubber include polyaromatic hydrocarbons, CO, SO_2, NO_2 and, HCl. The residual ash also pollutes the soil [2]. According to the Iranian Tire Industry Association, 280,000 tonnes of tires entered the

Iranian car market last year and, is expected to produce more than 200,000 tonnes of the waste tire in a year.

The recycling and returning to the car industry cycle In Iran has been provided in two factories at Qom and Yazd province. Their recycling capacity is 8,000 tonnes waste tire per year [5]. Of course, other factories in the country also convert about 32,000 tons of waste tires into granule and tire powder. In other words, 160,000 tonnes of waste tires are thrown away annually in Iran. Whereas in Europe, 3.2 million tonnes of tires were eliminated in 2009, of which 18% was reused, 38% was recycled and, 40% was burned to generate energy. In the US, in 2014, 95.9% of the 3.824 million tonnes of waste tires were recovered in various applications [6]. Tire burning, its use as fuel, pyrolysis, and carbon black production are fine-tuning methods. One disadvantage of pyrolysis is the production of soot and air pollution. The use of tire as a fuel is not commercially attractive because carbon black produced from the tire is very expensive and of lower quality than carbon black produced with petroleum compounds [7].

Global warming is a phenomenon that has far-reaching consequences. Reducing the consumption of fossil fuels and recycling are just two ways to reduce the devastating effects of global warming. Recent research has confirmed that the use of materials with high insulation properties can significantly reduce energy consumption [1].

One of the environmentally friendly ways is to use a waste tire and insert it into cement mortar to replace some of its natural components such as sand. For this purpose, the tires are cut in sizes 0.75 ~ 5.75 mm. First, the rubber is crushed to a large scale, and then the steel wires and woven components are separated and re-machined. The operation can be performed in four modes, at ambient temperature, and under humid conditions, at high temperature, ambient temperature and freezing cold. To be done. Tire researchers divided the waste crumb tire into three categories [8].

1. Torn tire or tire chip, tires are split in two stages initially with the size 300 ~ 430 mm long and 100 ~ 230 mm full, and in the second stage, the length is reduced to 100 ~ 150 mm and width to 13 ~ 76 mm.
2. Crushed tire, this type of fine-grained tire is obtained using special rollers that cut the tire pieces to 0.425 ~ 4.75 mm.
3. Ultra-thin cutting, the size of this type depends on the type of equipment used. The particles with a size of 0.0047 ~ 0.0005 mm can be reached by the micron rolling process.

Autoclaved concrete was invented in 1924 by a Swedish architect-engineer. The density of ordinary concrete is about 2400 kg/m^3. The density of lightweight concrete is usually about 300 ~ 1800 kg/m^3 [8]. Since the compressive strength is proportional to the density, the compressive strength decreases as the density decreases. Autoclaved Aerated Concrete (AAC) is a lightweight or porous gaseous concrete. Aerated concrete is a type of cement or lime mortar that is classified as lightweight concrete. In this concrete, the air holes are trapped by the appropriate aeration agents inside the mortar bed. The most common method for preparing aerated concrete is gas concrete and cavity formation. In this method, the chemicals in the liquid or plastic phase are mixed with lime or cement mortar. After the volume is increased, the created gas is removed, and the structure is left full of pores. In this method, aluminum powder, hydrogen peroxide with bleach powder and calcium carbide are most commonly used to generate hydrogen, oxygen, and acetylene respectively. Among these materials, aluminum powders are used as the most critical aeration agent [7]. The efficiency of the aluminum powder in the process depends on the fine powder, the purity and the alkali content of the cement, as well as the capability of the gas to be produced and its removal before the mortar is hardened. If Portland cement with a low alkali content is used, the addition of sodium hydroxide or lime provides the required alkali content [9]. Due to the size and lightness and ease of installation of autoclaved aerated concrete blocks in all thicknesses, the performance speed is three times higher than other construction materials.

Experimental

a. Materials: Rubber particles used in this study have been obtained from mechanical shredding of waste tire. The crumb rubber particles were passed from 1.19, 0.841, and 0.4 mm sieves consecutively. Fig. 1 shows the various sizes of crumb rubber. Aluminium powder (>90%, the density of 2.7 g/cm³ and average particle size of 0.177 mm) and calcium hydroxide (≥ 96.0 %) were purchased from Merck Germany. Silica-based sand with a grain size of 0.177 mm from Mastan-Abad-Nir Ardabil company, Gypsum plaster powder with a grain size of 0.177 mm from Hashtood-Maraghe plaster company and pozzolana cement were purchased from Arta-Ardabil Cement company. Deionized water was used for all preparations.

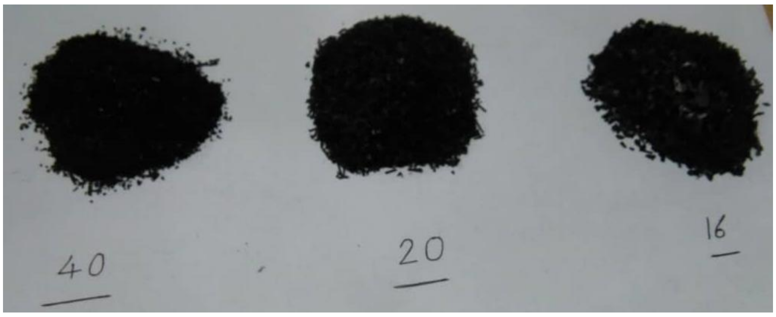

Fig. 1. sieved crumbed rubber with mesh No. of 40 (a), 20 (b) and 16 (c).

b. Production of rubber/AAC composites: All experiments were done in an air-conditioned laboratory at temperature 30±10 °C and relative humidity 28±6%. All samples were prepared with a fixed platform for ease of production and comparison. At first, 956 grams of sand were mixed with 1123 grams of water, and for concrete specimens with rubber, rubber powder (5 wt% of the solid ingredients) was added to the mixture. After three minutes of mixing, 410 g of cement was added. One minute later, 30 g gypsum and 122 g lime were poured into cement blend. The slurry continuous mixing at 35 °C for 5 minutes. It should be noted that from the beginning of the operation to the stage of slurry discharge into the molds, mixing is carried out at continuous speed. Then 1.48 g of aluminum powder was added to the cement blend and continue mixing to 37 °C. Finally, the slurry transferred to the 15 × 15 × 15 cm mold. Immediately the frame was placed in an autoclave at 180 °C and 12 bar for 14 hr. After leaving autoclave, the rubber/AAC composites was cute to 10 × 10 ×10 cm specimen and dried at 105 °C for 24 hr. The dried samples were used for analysis. The images of the prepared samples were shown in Fig. 2. Also, table 1 shows the composition of the raw materials in the rubber/AAC composites.

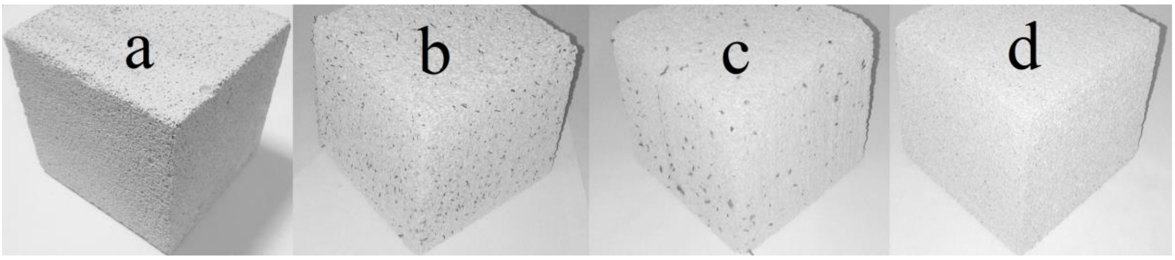

Fig 2. Image of the prepared samples

Table 1. Compositions percentage of the ingredients in the preparation of rubber/AAC composites

Sample	Density (**kg**/m^3)	Solid Phase							Water (g)
		Average rubber particle size (mm)	Rubber (wt%)	Sand (wt%)	Cement (wt%)	Aluminium (wt%)	Lime (wt%)	Gypsum (wt%)	
AAC	519	-	0	62.9	26.9	0.1	8.1	2	1123
R16/AAC	725	1.19	5	59.9	25.51	0.09	7.6	1.9	1123
R20/AAC	622	0.841	5	59.9	25.51	0.09	7.6	1.9	1123
R40/AAC	630	0.4	5	59.9	25.51	0.09	7.6	1.9	1123

c. Characterization: The Eudiometer was used to obtain the optimum molding time. 0.07 grams of aluminum powder and 2.5 grams of lime were mixed at sealed ballon and the produced hydrogen conducted to a graduated cylinder. The results were shown in Fig. 3.

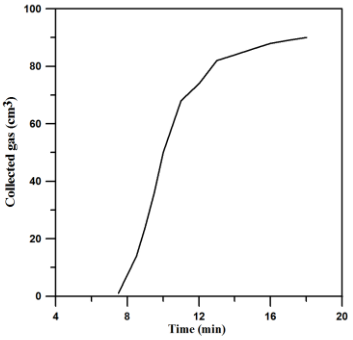

Fig.3 Produced hydrogen versus time.

For the bulk density test, The samples were cut into cubes (10×10×10 cm) and oven-dried at 60 ± 5 °C for 24 h, then at 80 ± 5 °C for 24 h, and finally at 105 ± 5 C until a constant weight was achieved. The volume and mass of the specimens were determined and used to calculate the volume density as follows:

$$\rho=M/V$$

Where ρ is the volume density, M is the mass, and V is the volume of a specimen. Compression displacement curves were obtained by using the SANTAM instrument (STM-250, Iran). The compressive strength of AAC specimens was tested according to the Chinese Standard GB11968-2008 “Test methods of autoclaved aerated concrete”. The compressive strength specimens were 10 × 10 ×10 cm. For ease analysis, compressive strength test results were multiplied by negative one. Acoustics determination of sound absorption coefficient was measured in impedance tube B&K Standing Wave4002 instrument. Two different rod-like specimens (diameter of 29 and 99 mm with 20 mm height) were used at two different frequency ranges: high-frequency (1000, 2000, and 4000 Hz) and low frequency (125, 250, and 500 Hz). Measurements were carried out according to the standing wave method. A speaker sets up a loud sound field in a tube in which terminated by the specimen. Then, the ratio between the maximum and minimum sound pressure was measured. The absorption coefficient of the sample for a zero degrees sound wave was calculated [10].

Results and discussion

The time it takes for the mixture to be in the autoclave at 180 °C and pressurized to 12 bar after adding aluminum powder is very useful on the aerated concrete properties. The

Eudiometer is used to find the best time. As shown in Fig.3, it is essential to receive proper pressure in about seventeen minutes after mixing the aluminum powder with the cement mixture. Being in earlier times cause hardening the bubble wall before reaching a larger size, so increases the density of the specimen [9].

On the other hand, the bubbles formed over a long time are removed from the cementitious matrix and decrease its density [9]. As shown in table 1, the density of rubber contained samples higher than AAC. In AAC sample, aluminum/lime ratio is higher than other rubber content samples. As expected, decreasing this ratio cause lower bubble generation and higher density. The presence of smaller rubber particles insert more micropores into the cement structure, thus, density decreases. In the R40/AAC sample, according to previous report [11], the average pore size is about 0.5 mm, which is more significant than the average of rubber particle size used in the R40/ACC sample. So, the density of R40/ACC is a little higher than R20/ACC.

The mechanical properties of samples are closely related to their bulk densities because they depend significantly on its porosity and pore structure [11]. Fig. 4 shows the compressive strength of AAC specimens. To facilitate the analysis of the compressive strength test results, they are multiplied by a negative one.

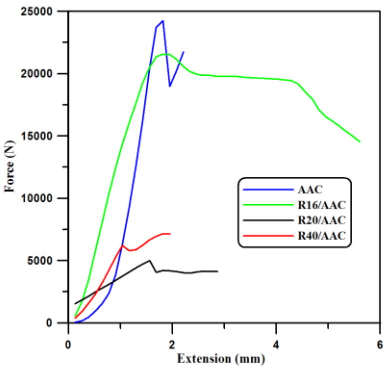

Fig. 4 Compression displacement curves of prepared samples

It is evident that the insertion of rubber particles case plastic behavior of AAC composites. In the R16/AAC sample, because of bigger rubber particles, the result has a significant increase in mechanical properties. We believe that the reinforcement mechanism, in this case, has changed to short rubber fibers/cement matrix. As previously state, R40/AAC has a higher density than R20/AAC. The results of the compression test also confirm the density data. In R40/AAC, rubber particles are very small compared with pore size, so they act as stress concentration points. The results of sound absorption analysis were depicted in Fig.5. Obviously, the presence of rubber particles in the cement matrix has sound absorption properties. Although the results at low frequency (125 and 250 Hz) are the same, at middle frequency, starts differences. At high frequency, the results show rubber dispersed particles.

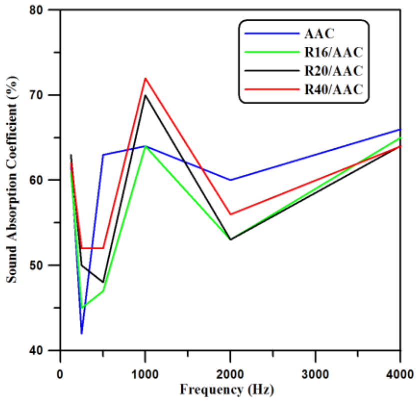

Fig. 5 Sound absorption coefficient of AAC samples.

Conclusions

Autoclaved aerated concrete composites were produced with different rubber particle size. The smaller rubber particles resulted in a lower density. The results shows, increasing the size of the rubber particles leads to an increase in the plastic area and when the height of rubber particle size reaches about 1.2 mm, the product becomes very tough. The presence of rubber particles in the cement matrix has sound absorption properties. The rubber/AAC composites show excellent hi-frequency sound absorption performance.

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References

[1] Li, Yang, Shuai Zhang, Ruijun Wang, and Faning Dang. "Potential use of waste tire rubber as aggregate in cement concrete–A comprehensive review." Construction and Building Materials, 225, 1183-1201 (2019).

[2] Thomas, Blessen Skariah, and Ramesh Chandra Gupta. "A comprehensive review on the applications of waste tire rubber in cement concrete." Renewable and Sustainable Energy Reviews, 54, 1323-1333 (2016).

[3] Y. Park, A. Abolmaali, M. Mohammadagha, S. Lee, "Structural performance of dry-cast rubberized concrete pipes with steel and synthetic fibers", Constr.Build. Mater. ,77 ,218–226 (2015).

[4] A.A. Gheni, H.H. Alghazali, M.A. ElGawady, J.J. Myers, D. Feys, "Durability properties of cleaner cement mortar with by-products of tire recycling", J. Cleaner Prod. ,213, 1135–1146 (2019).

[5] http://www.tireia.ir/public/en /information.aspx.

[6] RubberManufacturer'sAssociation.USA (2014).

[7] Narayanan, N., and K. Ramamurthy. "Structure and properties of aerated concrete: a review." Cement and Concrete composites 22, no., 5, 321-329 (2000).

[8] Benazzouk, A., O. Douzane, K. Mezreb, and M. Quéneudec. "Physico-mechanical properties of aerated cement composites containing shredded rubber waste." Cement and Concrete Composites, 28, no. 7 650-657 (2006).

[9] Jerman, Miloš, Martin Keppert, Jaroslav Výborný, and Robert Černý. "Hygric, thermal and durability properties of autoclaved aerated concrete." Construction and building materials, 41, 352-359 (2013).

[10] Sukontasukkul, Piti. "Use of crumb rubber to improve thermal and sound properties of pre-cast concrete panel." Construction and Building Materials 23, no. 2, 1084-1092 (2009).

[11] He, Tingshu, Rongsheng Xu, Yongqi Da, Renhe Yang, Chang Chen, and Yang Liu. "Experimental study of high-performance autoclaved aerated concrete produced with recycled wood fiber and rubber powder." Journal of Cleaner Production (2019).