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Original Research Article

The Influence of Waste Tire Powder on Mechanical and Acoustic Properties of Autoclaved Aerated Concrete

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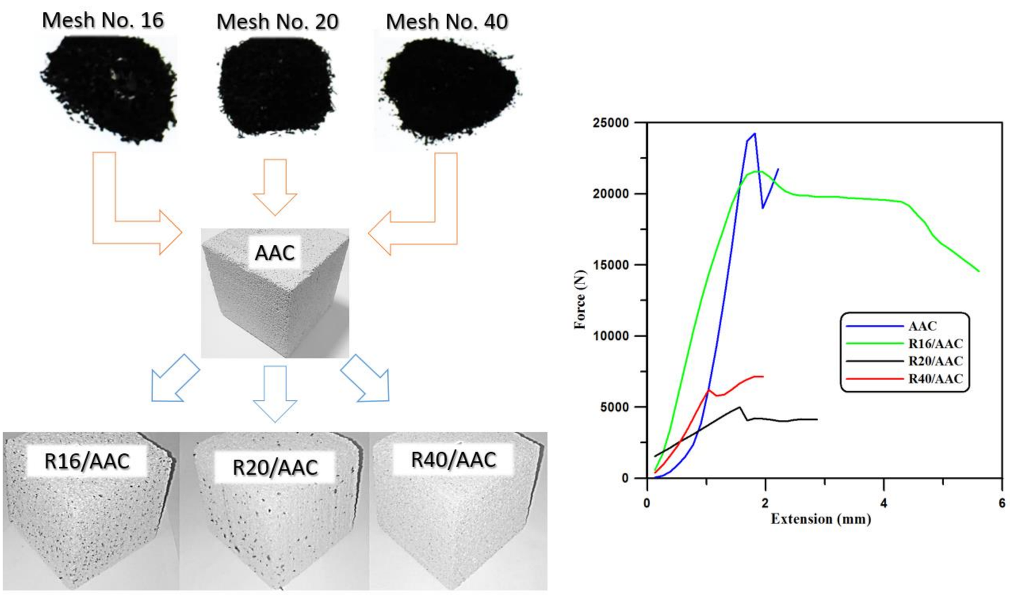
ABSTRACT

Waste tires left in the environment are now becoming a global problem. On the other hand, the use of minerals consumed in the construction industry, in addition to being expensive, may reduce the natural mineral reserves around us. Using waste tire powder to make Autoclaved Aerated Concrete (AAC) is cost-effective. The presence of rubber powder inside the AAC leads to the toughness of the concrete and increases the elongation at break, and gives the plastic behavior to the concrete. In this study, rubber powder of different sizes was used as a filler inside the autoclaved concrete. The presence of elastic rubber particles enhances the sound absorption of AAC. The results revealed that by changing the amount of aluminum added to the concrete mixture, the impact of rubber addition on the density of AAC could be controlled. Reducing the particle size of tire powder also increases the sound absorption of AAC.

GRAPHICAL ABSTRACT



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Introduction

The issue of waste tires is a major environmental problem. Waste tires released in nature are seriously threatening the environment [1]. Disposal waste tires are used in various ways, such as burning [2] and landfilling [3], mulching on the sports field, and asphalt bond modifier [4]. Air, water, and soil pollution through stored waste tires results in environmental, health, and economic issues [2]. Approximately 1.5 billion tires are manufactured worldwide 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 unique 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 tons of tires entered the Iranian car market last year. It is expected to produce more than 200,000 tons of waste tires in a year.

The recycling and returning to the car industry cycle In Iran has been provided in two factories in Qom and Yazd province, Iran. Their recycling capacity is 8,000 tons of waste tires 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 tons of waste tires are thrown away annually in Iran. In Europe, 3.2 million tons of tires were eliminated in 2009, of which 18% were reused, 38% were recycled, and 40% were burned to generate energy. In the US, in 2014, 95.9% of the 3.824 million tons 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 tire application as a fuel is not commercially noteworthy because carbon black produced from the tire is very costly and of lower quality than carbon black produced with petroleum compounds [7]. Recently, Zamiraei *et al*. [8] reported the application of waste tires for crude oil absorption.

Global warming has overall outcomes. Reducing the consumption of fossil fuels and recycling are just two ways to decrease the destructive effects of this phenomenon. Recent research has confirmed that compounds with high insulation can significantly diminish energy consumption [1]. Rubber powder is used in other applications such as rubberized asphalt, rubberized bitumen, reclaim rubber, Rubber ground flooring, Brake pad, and Rubber conveyor [2].

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 [9]. 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: room temperature, humid conditions, high temperature, room temperature, and cold [10]. Tire researchers divided the waste crumb tire into three categories [11].

- Torn tires or tire chips are split into 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 the width to 13~76 mm.

- Crushed tire, this fine-grained tire is obtained using special rollers that cut the tire pieces to 0.425~4.75 mm.
- 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 using 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 [11]. The compressive strength declines with the density since it is proportional to the density. Autoclaved aerated concrete (AAC) is lightweight or porous gaseous concrete. It is a type of cement or lime mortar categorized as lightweight concrete. The appropriate aeration agents trap the air holes inside the mortar bed in this concrete. 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 increases, 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. 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, the gas's capability to be produced, and its removal before the mortar is hardened. If Portland cement with a low alkali content is used, the addition of NaOH or lime provides the required alkali content [12]. Due to the size, lightness, and ease of installing autoclaved aerated concrete blocks in all thicknesses.

In this study, rubber particles with three different particle size distributions/mesh were prepared via mechanical shredding of waste tires. Waste rubber particles were used to prepare rubber/Autoclaved Aerated Concrete composites to evaluate the effect of rubber addition on the mechanical and acoustic properties of AAC.

Experimental

Materials

Rubber particles used in this study have been obtained from mechanical shredding of waste tires. The crumb rubber particles obtained from buffing processes were passed consecutively from 1.19, 0.841, and 0.4 mm sieves. Figure 1 demonstrates the various sizes of crumb rubber. Aluminum powder (>90%, the density of 2.7 g/cm^3, 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.

Figure 1. Sieved crumbed rubber with mesh No. of 16, 20, and 40.

Production method of rubber/AAC composites

All experiments were done in an air-conditioned laboratory at 30±10 °C and relative humidity of 28±6%. All samples were prepared with a fixed platform for ease of production and comparison. At first, 956 gr of sand were mixed with 1123 gr 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 the cement blend. The slurry was mixed for 5 min at 35 °C.

It should be noted that mixing was carried out at continuous speed from the beginning of the operation to the stage of slurry discharge into the molds. Then 1.48 g of aluminum powder was added to the cement blend and continued mixing to 37 °C. Finally, the slurry was 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 the autoclave, the rubber/AAC composites were cut into 10×10 ×10 cm specimens and dried at 105 °C for 24 hr. The dried samples were used for analysis.

Characterization

The Eudiometer was used to obtain the optimum molding time. 0.07 gr of aluminum powder and 2.5 grams of lime were mixed at a sealed ballon, and the produced hydrogen was conducted to a graduated cylinder.

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:

$$\rho=M/V \qquad (1)$$

Where ρ is the volume density, M is the mass, and V is the volume of a specimen. Compression displacement curves were obtained 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. Compressive strength test results were multiplied by a negative one for ease of analysis. 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 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 [13].

Table 1. Composition of the ingredients in rubber/AAC composites

			Solid Phase						
Sample	**Density (kg/m³)**	**Average rubber particle size (mm)**	**Rubber (wt%)**	**Sand (wt%)**	**Cement (wt%)**	**Aluminium (wt%)**	**Lime (wt%)**	**Gypsum (wt%)**	**Water (g)**
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

Results and Discussion

The images of the prepared samples are presented in Figure 2. Also, Table 1 shows the composition of the raw materials in the rubber/AAC composites.

Figure 3 reveals the produced hydrogen versus time. The optimum molding time was obtained based on Eudiometer.

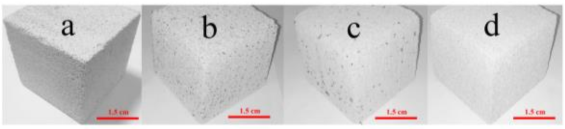

Figure 2. Image of the prepared samples (a) AAC, (b) R16/AAC, (c) R20/AAC, (d) R40/AAC

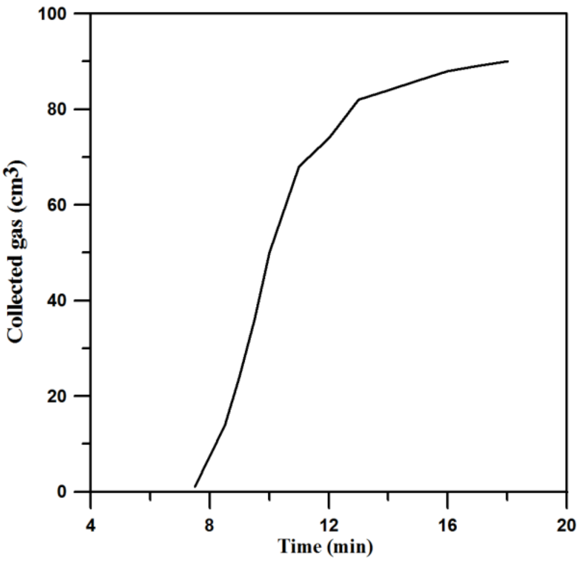

Figure 3. Produced hydrogen versus time

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 advantageous for the aerated concrete properties. The Eudiometer is used to find the best time. As shown in Figure 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 causes hardening of the bubble wall before reaching a larger size, increasing the specimen's density [12].

On the other hand, the bubbles formed over a long time are removed from the cementitious matrix and decrease its density [12]. As shown in table 1, the density of rubber contained samples higher than AAC. In the AAC sample, the aluminum/lime ratio is higher than in other rubber content samples. As expected, decreasing this ratio cause lower bubble generation and higher density. Smaller rubber particles insert more micropores into the cement structure. Thus, density decreases. In the R40/AAC sample, according to a previous report [14], the average pore size is about 0.5 mm, which is more significant than the average 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 their porosity and pore structure [14]. Figure 4 depicts the compressive strength of AAC specimens. To facilitate the analysis of the compressive strength test results, they are multiplied by a negative one.

The insertion of rubber particles case the plastic behavior of AAC composites. The mechanical properties improved significantly in the R16/AAC sample due to the bigger rubber particles. We believe that the reinforcement mechanism, in this case, has changed to short rubber fibers/cement matrix. As previously stated, 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 tiny compared with pore size, acting as stress concentration points.

The results of sound absorption analysis are depicted in Figure 5. The rubber particles in the cement matrix have 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. The noise reduction coefficient (NRC) parameter can be used to easily analyze sound absorption data. NRC is obtained by averaging sound absorption values at four frequencies: 250, 500, 1000, and 2000 Hz. [14]. NRC parameter values for AAC, R16/AAC, R20/AAC and R40/AAC samples were 57.25, 52.25, 55.25 and 58, respectively. In all R/ACC samples, the weight percentage of rubber powder is equal. Increasing the size of rubber powder due to lack of uniform distribution and increasing density reduces NRC. Reducing the particle size of rubber powder causes better dispersion, non-interference in the formation of fine gas cavities, decreases the density and increases the amount of sound absorption.

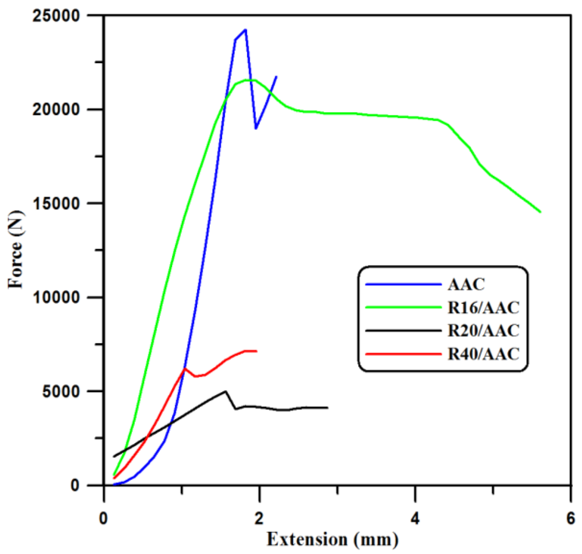

Figure 4. Compression displacement curves of prepared samples

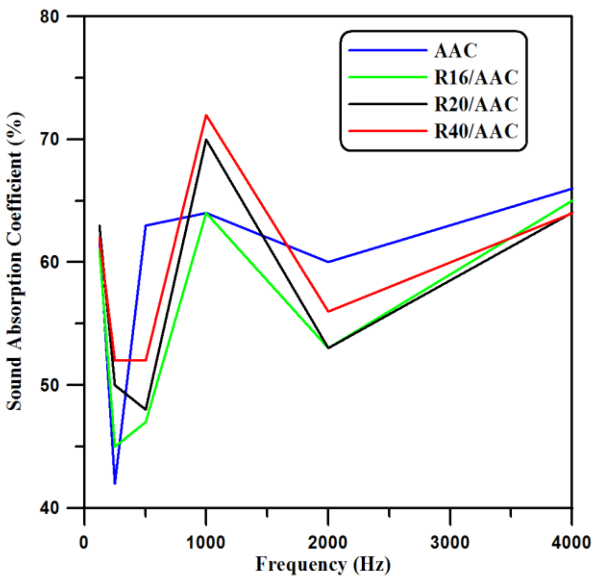

Figure 5. Sound absorption coefficient of AAC samples

Conclusion

Autoclaved aerated concrete composites were produced with different rubber particle sizes. The smaller rubber particles resulted in a lower density. The results demonstrated that increasing the size of the rubber particles leads to an increase in the plastic area. When the rubber particle size reached about 1.2 mm, the product became very tough. The presence of rubber particles in the cement matrix has excellent absorption properties. The rubber/AAC composites show excellent hi-frequency sound absorption performance. The presence of rubber powder in the R40/AAC sample increases the noise reduction coefficient from 57.25 to 58.

Disclosure statement

No potential conflict of interest was reported by the authors.

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