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The Effects Strength & Density of Autoclaved Aerated Concrete Containing Recycled Rubber (AAC-RR) on Insulation Application

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ABSTRACT

This research presents the properties of Autoclaved Aerated Concrete (AAC) based Recycled Rubber (AAC-RR) is used as a partial replacement for sand in lightweight panels. Adding recycled rubber helps decrease environmental waste, improve sustainability, and enhance the material's strength, modulus young, modulus rupture and density, potentially reducing production expenses. The AAC-RR were made by substituting sand with recycled rubber at varying levels of 0%, 5%, 10%, 15%, 20%, and 25%, utilizing typical components such as cement, sand, water, and 1% aluminum paste. The findings from the experiment show that the AAC-RW of 10% recycled rubber offers the optimal combination of strength and sustainability, with a dry compressive strength of 1.960 MPa, a density of 0.867 g/cm³, and a Young's modulus of 0.680 GPa in line with the desired density of 750 kg/m³. The 10% AAC-RW provides potential to be applied into insulation panel due to its low weight characteristics. It is revealed that AAC-RR from recycled rubber materials help in improve both performance and environmental benefits.

1. Introduction

Autoclaved Aerated Concrete (AAC) is a lightweight, energy-efficient construction material that has become popular in non-structural uses like partition walls, floors, and roofs, owing to its superior thermal and acoustic insulation characteristics. Although these benefits exist, AAC's lower compressive strength and density restrict its application in structures that need greater load-bearing capability. To overcome these challenges, researchers have investigated the integration of recycled

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rubber, especially from old tires, into AAC. This alteration, referred to as recycled rubber-modified AAC (AAC-RR), seeks to improve the material's flexibility, impact resistance, and insulation characteristics while tackling environmental issues connected to tire disposal. Recycled rubber is a potential additive that may enhance the overall functionality of AAC, rendering it a more adaptable material for a wider array of uses [1]. This research investigates the impact of recycled rubber on the compressive strength, density, and insulating characteristics of AAC, emphasizing its appropriateness for insulation uses. The objective is to assess how different quantities of recycled rubber affect the mechanical and insulation characteristics of AAC, thus aiding in the creation of more sustainable and effective construction materials.

The impact of adding recycled rubber to AAC, especially regarding compressive strength and density, has been extensively researched. Compressive strength serves as a crucial indicator for assessing AAC's appropriateness for structural uses, yet several studies have shown that incorporating recycled rubber diminishes the material's compressive strength. This decrease is mainly caused by the spaces formed by the rubber particles, which lower the total mass and strength of the material. For example, Gajendran *et al.,* noted a 20% decline in compressive strength when 10% recycled rubber was incorporated into AAC, lowering the strength from 6.0 MPa to 4.8 MPa [2]. While this reduction in strength restricts its application in load-bearing scenarios, the rubber-modified AAC showed enhanced resilience, flexibility, and impact resistance, rendering it appropriate for non-structural purposes such as partition walls and external cladding. Likewise, Abdullah *et al.,* observed that the compressive strength of AAC reduced from 4.5 MPa to 3.5 MPa upon incorporating 15% recycled rubber, yet it still retained sufficient strength for non-structural purposes like cladding. Kakali *et al.,* noted a comparable reduction in compressive strength when 10-20% of recycled rubber was incorporated into AAC, lowering the strength from 5.5 MPa to approximately 4.0-4.3 MPa. Nonetheless, the energy absorption capability of the material enhanced, rendering it more appropriate for applications that require energy efficiency and noise insulation [3]. Rahman *et al.* discovered that the compressive strength of rubber-modified AAC varied from 3.2 MPa to 4.5 MPa based on the rubber content; despite the reduction in strength, the material remained suitable for non-load bearing uses, especially in structures that emphasize insulation [4].

Regarding density, incorporating recycled rubber into AAC typically leads to a decrease, enhancing the material's lightweight characteristics and boosting its thermal and acoustic insulation features. Gajendran *et al.,* noted that when 10% recycled rubber was added, the density of AAC reduced from 650 kg/m³ to 550 kg/m³, enhancing the material's manageability and thermal insulation properties. Abdullah *et al.,* noted a comparable decrease in density, as the material's density fell from 600 kg/m³ to 500 kg/m³ upon adding 15% recycled rubber, which improved its energy efficiency and transportability. Kakali *et al.,* discovered that the density of AAC reduced from 600-650 kg/m³ to 530-560 kg/m³ with the inclusion of 10-20% recycled rubber, which resulted in a lighter product and enhanced its acoustic and energy-absorbing characteristics. Likewise, Rahman *et al.,* indicated a decrease in density from 650 kg/m³ to 480-550 kg/m³ upon adding 5-30% recycled rubber, which enhanced thermal insulation and handling.

Incorporating recycled rubber into Autoclaved Aerated Concrete (AAC) results in decreased compressive strength and density, affecting the material's use in construction. Although the compressive strength drops by approximately 10-30% depending on the rubber content, the material is still appropriate for non-load bearing uses where flexibility, insulation, and impact resistance are emphasized. The decrease in density, reaching as much as 20%, leads to a lighter substance that provides enhanced thermal and acoustic insulation features, rendering AAC-RR suitable for application in partition walls, cladding, and flooring within energy-efficient structures. Nonetheless, additional studies are needed to refine the rubber content and curing methods to strike a balance between compressive strength and insulation characteristics, facilitating AAC-RR's wider application in the construction sector [5].

2. Methodology

2.1 Preparation of AAC-RR samples

The recycled rubber used in this study was sourced from Soon Huat Rubber & Trading Sdn Bhd in Parit Sulong, Johor. The rubber waste was processed into powder form at the Concrete Technology Workshop, UTHM Pagoh, utilizing a shredding machine. Following shredding, the rubber was sieved with a Copper Technology Sieve Shaker according to British Standard Specification for Test Sieves (BS 410), targeting a particle size of 0.5 ± 0.05 mm using a 0.5 mm aperture sieve, as illustrated in Figure 1. Particles that did not meet the target size were excluded from further analysis and production processes. The raw materials for each sample were weighed based on the mixture proportions listed in Table 1, with varying amounts of recycled rubber (RR).

Fig. 1. Material preparation of recycled rubber (RR)

Figure 2 illustrates the process detailed requires thorough material preparation and curing in order to produce a composite material. Precise measurements are taken for the ingredients - sand (40%), recycled rubber (30%), lime (7%), cement (23%), and water (0.65%) - to maintain consistency. Errors are kept within a range of 0.65% for powder and water, and 0.1% for aluminium powder. The aluminium powder reacts with the lime and water, producing hydrogen gas, which causes the mixture to expand and form air pockets, resulting in AAC structure. The blend is mixed with an Allefix 2100W Electric Mixer for 15 minutes, then aluminium powder (0.1%) is added and mixed for another 15 seconds. Once the mixture has partially set, the soft materials are removed from the moulds and the slurry that is obtained is poured into moulds, filling up to two-thirds of the mould, and then gently shaken to eliminate any air bubbles. A reaction of expansion takes place, finishing the filling of the mould in approximately 30 minutes. Following pre-curing at room temperature for 2 hours, the slurry is hydrothermally cured in an autoclave at temperatures ranging from 180°C to 200°C and 13 bar pressure for 12 hours. This steam curing process causes the chemical reaction between lime and silica, forming calcium silicate hydrate, which binds the material and gives it strength and durability. Following autoclaving and cooling, the blocks go through the cutting process as the last stage of the AAC block construction process. In this stage, cutting wires or automated cutting machines are used to gently cut the solidified, aerated slurry into the appropriate block size. The cutting procedure is extremely accurate, guaranteeing consistent block shapes and sizes. Figure 3 shows the different composition of slurry in the box mould of AAC-RR for sand replacement method.

Fig. 2. Process of fabrication AAC-RR

Table 1
The different of AAC-RR as sand replacement

Sample number	Sample of different ratio	Replacement		Lime (%)	Cement (%)	Aluminum Paste (%)	Water (%)
		Sand (%)	RR (%)				
CS-0	Control Sample (CS)	70.00	0.00	7	23	0.1	0.65
A-05	Sample A_65S _5RR	65.00	5.00	7	23	0.1	0.65
B-10	Sample B_60S _2G_10RR	60.00	10.00	7	23	0.1	0.65
C-15	Sample C_55S _2G_15RR	55.00	15.00	7	23	0.1	0.65
D-20	Sample D_50S _2G_20RR	50.00	20.00	7	23	0.1	0.65
E-25	Sample E_45S _2G_25RR	45.00	25.00	7	23	0.1	0.65

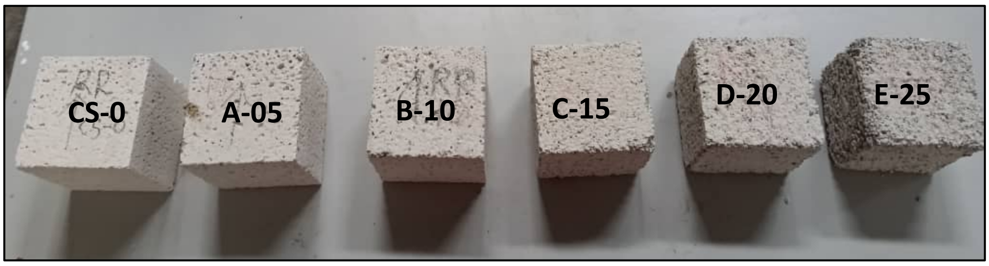

Fig. 3. The different composition of slurry in the box mould of AAC-RR for sand replacement method

3. Results

3.1 Compressive Strength Analysis

The AAC-RR properties including compressive strength, Young's Modulus, and modulus of rupture (MOR), were investigated. The results, summarized in Table 2, indicate that these properties were affected by the RR content. With the appropriate composition, RR was found to improve the compressive strength of the samples.

Table 2
The compressive strength, specific strength, modulus Young and modulus of rupture of AAC with different RR contents

Sample number	Compressive strength (MPa)	Modulus Young (GPa)	Modulus rupture (MPa)
CS-0	2.142	0.561	1.285
A-05	1.955	0.496	1.173
B-10	1.960	0.680	1.176
C-15	1.870	0.491	1.138
D-20	1.541	0.289	0.925
E-25	0.468	0.058	0.281

In line with findings from other studies on rubber-modified concrete, the compressive strength data for AAC-RR (Autoclaved Aerated Concrete with Recycled Rubber) based on Figure 4 indicates a noticeable decline as the rubber component rises. The control sample (CS-0) in the current dataset has a compressive strength of 2.142 MPa; nevertheless, the compressive strength gradually decreases as the proportion of recycled rubber rises. The strength lowers marginally to around 1.96 MPa at A-05 and B-10, which contain 5% and 10% rubber, respectively. However, the strength declines more dramatically when the rubber content increases to 15% in C-15 and 20% in D-20, reaching 1.541 MPa. The largest loss is shown at E-25, when a compressive strength of just 0.468 MPa, or more than 70% less than the control sample, is obtained with 25% recycled rubber.

This decrease in compressive strength is in keeping with findings from other studies on concrete that has been treated with rubber. For instance, Bairagi *et al.,* discovered that adding recycled rubber to concrete considerably decreased its compressive strength because the rubber's poor stiffness and flexibility make it unable to endure compressive stresses [6]. Rubberized concrete, according to Plati *et al.*, demonstrated decreased compressive strength because of the inadequate link between the rubber particles and the cement matrix, which lowers the material's overall capacity to withstand compressive pressures [7]. This tendency is shown in the current AAC-RR dataset, where a larger rubber content causes increased void formation and material deterioration under stress.

Furthermore, Ozen *et al.,* pointed out that rubber-modified AAC exhibits comparable patterns, with a higher percentage of recycled rubber leading to a decrease in strength, while it could still function well in non-structural applications [8]. According to the statistics for AAC-RR, the material can still be helpful in applications like partition walls and thermal insulation panels, where lightweight and thermal qualities are more important than high compressive strength, even though its compressive strength has dropped. The intrinsic characteristics of rubber are mostly responsible for the decrease in compressive strength caused by the addition of recycled rubber. According to Bairagi *et al.,* rubber particles are less stiff than conventional aggregates, increasing the composite material's flexibility and decreasing its resistance to compressive pressures [9]. The concrete's strength is further diminished by the spaces the rubber particles generate, which lessen the concrete's density. Stress transmission is less effective due to the poor link between the rubber and the cement matrix, which helps explain why AAC-RR has been shown to have a lower compressive strength [10].

All things considered, the compressive strength result for AAC-RR agrees well with previous studies on AAC and rubberized concrete. Since rubber particles in the matrix are flexible and have a weak connection, an increase in rubber content always results in a drop in compressive strength [11]. According to these results, AAC-RR is a good choice for non-structural applications where load-bearing capacity is less significant than thermal insulation, impact resistance, and lightweight characteristics. Prospective investigations may concentrate on maximizing the rubber content and investigating methods or additions that might enhance the material's durability while preserving its environmental advantages [12].

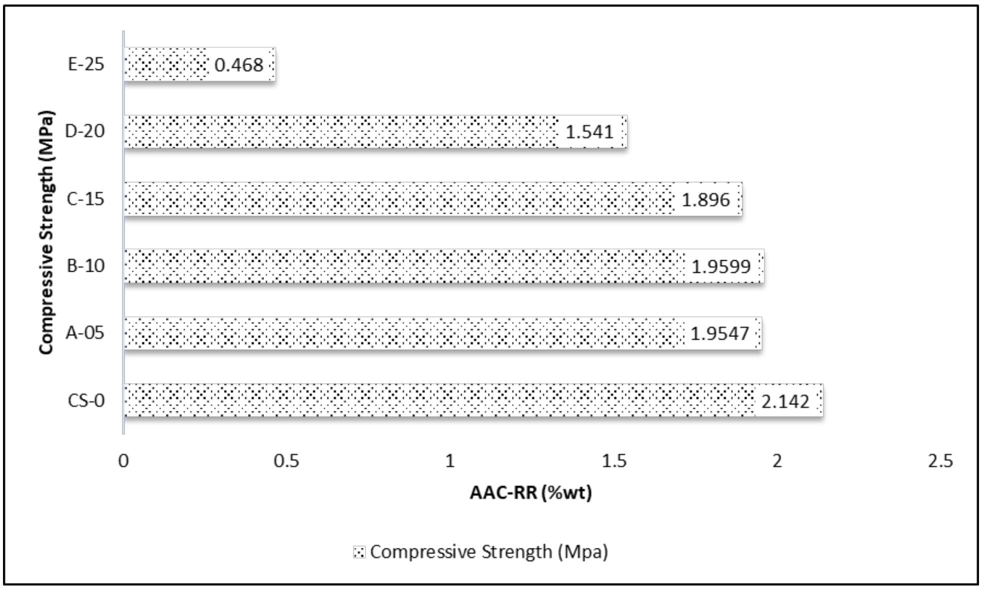

Fig. 4. The compressive strength of AAC with different RR contents

3.2 Modulus Young & Modulus Rupture Analysis

By incorporating recycled rubber into Autoclaved Aerated Concrete (AAC), AAC-RR (Autoclaved Aerated Concrete with Recycled Rubber) is a novel way to build materials. Incorporating recycled rubber, often from old tires, is a sustainable way to cut waste and encourage green building techniques [13]. However, this alteration affects a number of AAC mechanical characteristics that affect the material's performance in different structural applications, including compressive strength, Young's modulus, and modulus of rupture. The dataset's findings in Figure 5 indicate that compressive strength and modulus of rupture decrease with increasing rubber content, which is consistent with other studies on AAC and rubber-modified concrete (RMC). AAC-RR is better suited for non-load-bearing applications where flexibility, low weight, and thermal insulation are more important than high structural strength because of these qualities.

According to the findings in Figure 5, Young's modulus decreases from 0.561 GPa to 0.058 GPa throughout the same range of samples, and compressive strength decreases from 2.142 MPa for CS-0 to 0.468 MPa for E-25 as the rubber percentage rises. Likewise, the modulus of rupture drops for E-25 from 1.285 MPa to 0.281 MPa for CS-0. These patterns align with research on rubberized concrete, where the use of rubber is linked to properties like flexibility and decreased stiffness. According to Bairagi *et al.,* rubber alters concrete by reducing its stiffness and compressive strength because of its natural flexibility, which does not support the structural performance of concrete the way conventional aggregates would. AAC-RR's decreased strength emphasizes the application for uses for uses like partition walls or insulating materials where significant strength is not critical factor [14].

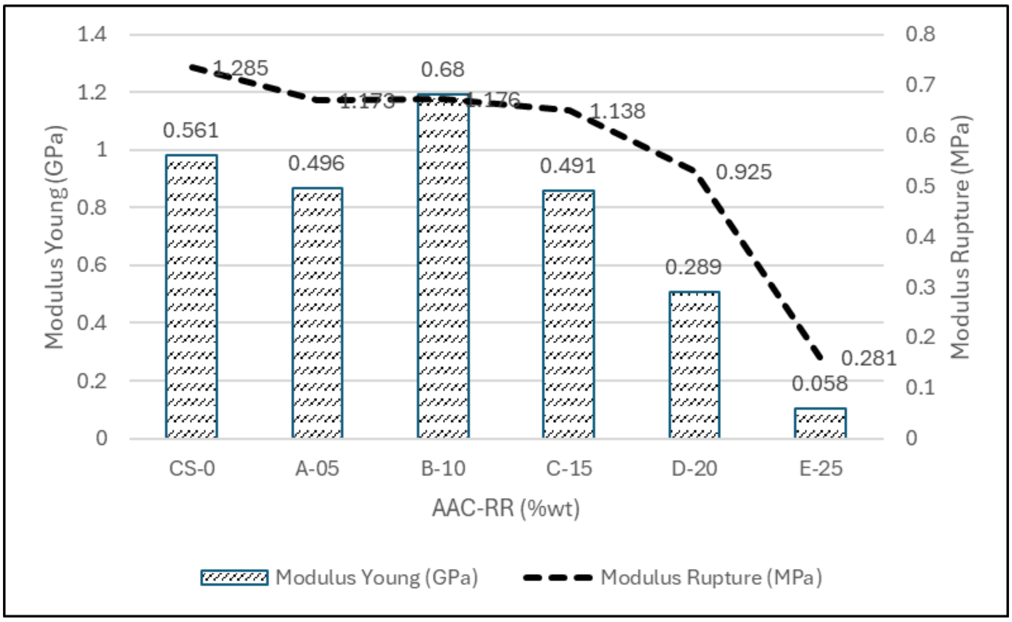

Fig. 5. The correlation between the modulus Young and modulus of rupture with compressive strength of AAC versus different RR contents

Plati *et al.,* studied that adding recycled rubber to concrete improved its thermal and acoustic insulation qualities but significantly decreased its mechanical strength, especially in its bending and compressive qualities, also supports the lower mechanical strength of AAC-RR [15]. The scientists also highlighted that rubber's flexibility, which impairs the material's resistance to both compressive and bending pressures, is the primary cause of the lower modulus of rupture and compressive strength. The results of the dataset were further supported by comparable research by Ozen *et al.,* who discovered that although rubberized AAC offered advantages in energy efficiency and impact resistance, its structural performance was naturally constrained by the low strength and stiffness of rubber [16]. Even though AAC-RR loses strength, its lighter weight and better insulating qualities make it a desirable choice for non-structural applications, particularly in structures that place a high value on energy efficiency. ASTM C1693-18 (Standard Specification for Autoclaved Aerated Concrete) states that higher-strength AAC can reach up to 12 MPa, whereas regular AAC usually shows compressive strength values between 2 and 8 MPa for non-structural applications. AAC-RR's status as a non-load-bearing material is further supported by the fact that its compressive strength ratings are within the lower range of conventional AAC. By lowering waste 7 encouraging circular 'economy principles in construction, recycled rubber provides a sustainable substitute for traditional building materials and is also consistent with green building techniques.

It is impossible to overestimate the environmental advantages of employing recycled rubber in building materials. Around 1.5 billion tires are thrown away annually worldwide, posing serious environmental problems. Tire waste may be less harmful to the environment by recycling rubber and using it in building materials like AAC. Additionally, a fundamental tenet of sustainable development is the utilization of recycled materials in construction, which is promoted by green building standards like LEED (Leadership in Energy and Environmental Design) [17]. Recycled rubber is used in construction projects to promote sustainability and lessen their carbon footprint. AAC-RR, in summary, is a viable option for non-structural building applications, particularly those requiring sustainable, lightweight, and energy-efficient materials. Although its modulus of rupture and compressive strength may not be as good as that of conventional AAC, the material's impact resistance and thermal insulation qualities make it appropriate for some uses, such as insulation panels and partition walls. The potential for AAC-RR to be a useful material in green building projects and energy-efficient construction lies in its capacity to better balance mechanical performance with environmental sustainability [18].

3.3 Bulk Density Analysis of AAC-RR

According to the results in Figure 6, there is a direct correlation between the samples' bulk density and mechanical characteristics including compressive strength, Young's modulus, and modulus of rupture. The material gets lighter and more porous as the bulk density drops, which results in a reduction in the material's stiffness, compressive strength, and bending resistance (Table 3). For example, CS-0 has the greatest modulus of rupture (1.285 MPa), Young's modulus (0.561 GPa), and compressive strength (2.142 MPa), all of which are correlated with its comparatively greater bulk density of 0.85 g/cm³. However, E-25 has the lowest values for all three mechanical properties—compressive strength (0.468 MPa), Young's modulus (0.058 GPa), and modulus of rupture (0.281 MPa)—with a bulk density of 0.75 g/cm³. These findings are consistent with accepted theories in the field of lightweight concrete.

Table 3
The sample weight, volume, bulk density and moisture content of AAC with different RR contents

Sample number	Sample weight (g)	Volume (cm³)	Bulk density (g/cm³)	Moisture content (%)
CS-0	972	1000	0.972	5
A-05	979	1000	0.979	5.5
B-10	867	1000	0.867	6
C-15	817	1000	0.817	7
D-20	809	1000	0.809	5
E-25	689	1000	0.689	6

Lightweight concrete materials like AAC-RR (Recycled Autoclaved Aerated Concrete) often exhibit this tendency, with decreased strength and stiffness due to greater porosity brought on by lower bulk density. The increased volume of air spaces, which erodes the material's internal structure, is the reason why mechanical characteristics fall as bulk density decreases. The density and internal structural performance of the material have a direct impact on compressive strength; materials with a higher density often perform better when supporting loads. This effect has been extensively established in the literature, including research by Ganesan *et al.,* and Bui *et al.,* which found a definite negative connection between AAC's mechanical strength and bulk density.

For instance, Ganesan *et al.,* showed that the compressive strength and modulus of rupture of AAC dramatically dropped when the bulk density was decreased by adding lightweight aggregates or recycled materials [19]. They ascribed this to the increased air content and porosity, which improved insulation but jeopardized the material's structural stability. Similarly, Bui *et al.,* discovered that replacing the aggregate content with recycled materials resulted in a more than 30% drop in the modulus of rupture of recycled AAC [20]. Their results suggest that recycled materials, although advantageous for the environment, sometimes come with trade-offs in mechanical qualities. This pattern was seen in this investigation, where the sample with the lowest bulk density, E-25, had the lowest modulus of rupture.

Cement and Concrete Composites [21] looked at the impact of recycled aggregates on the mechanical characteristics of AAC in another study. Their results demonstrated that although recycled aggregates help to cut the cost and environmental effect of concrete, they frequently lead to decreased stiffness and compressive strength, particularly when used in large quantities. This was especially noticeable in recycled AAC-RR samples, which demonstrated a significant fall in compressive strength as the material's bulk density dropped. The results of this investigation are consistent with their studies, which found that AAC materials manufactured from recycled aggregates had bulk densities and mechanical qualities that were typically lower than those made from fresh aggregates.

Additionally, Hassan *et al.,* investigated the connection between AAC-RR's mechanical characteristics and thermal insulation, finding that decreased bulk density greatly improved thermal insulation qualities but had a detrimental effect on compressive strength and modulus of rupture [22]. Their findings on lightweight AAC-RR materials, which showed enhanced energy efficiency in construction applications despite the lower mechanical qualities, were very clear examples of an inverse link between density and strength. The study underlined that although AAC-RR's reduced bulk density makes it unsuitable for big load-bearing buildings, its power to insulate against heat makes it perfect for partition walls and non-structural applications where load-bearing capacity is less crucial than energy efficiency. Accordingly, Kumar *et al.,* looked at the sustainability of employing recycled aggregates in AAC and discovered that AAC-RR with recycled content might have a major positive impact on the environment by lowering material waste and carbon footprint [23]. They did note, though, that adding recycled aggregates resulted in a decrease in mechanical qualities, particularly when bulk density was decreased. According to their research, using recycled aggregates reduced the environmental effect but necessitated carefully evaluating the mechanical qualities for each planned use.

The main conclusion drawn from prior studies and experimental data is that AAC-RR materials with lower bulk densities provide a trade-off between thermal insulation and mechanical strength. Although lower-density materials, like E-25, have a lower modulus of rupture and compressive strength, they are more appropriate for energy-efficient construction when thermal insulation takes precedence over structural properties. This aspect was also highlighted by Chin *et al.,* who came to the conclusion that lightweight AAC is best suited for non-load-bearing applications, especially in energy-efficient buildings where heat resistance and insulation are important factors [24]. With reduced bulk densities, AAC-RR offers a practical alternative for sustainable building applications, particularly in areas where energy efficiency is crucial, according to the study's findings and those of other studies. These materials must, however, be utilized carefully in applications that do not demand for significant structural strength since their mechanical qualities deteriorate with decreasing density. The trade-off between strength and insulating qualities emphasizes how crucial it is to choose the right material for a building project according on its particular requirements, whether those requirements be load-bearing capacity or thermal insulation [25].

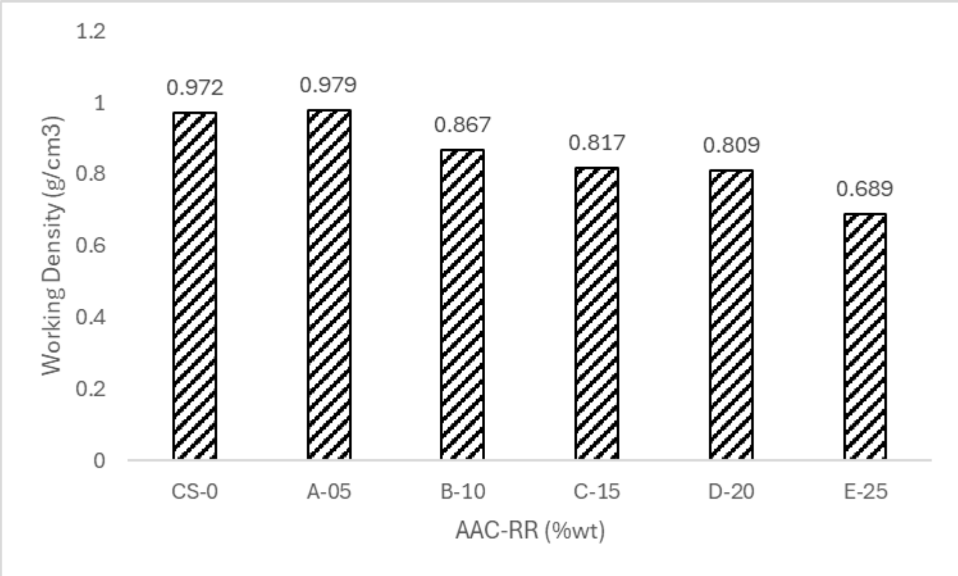

Fig. 6. The work density of AAC with different RR contents

4. Conclusions

In conclusion, the compressive strength, modulus of rupture, and Young's modulus of Autoclaved Aerated Concrete (AAC) all noticeably decline as the proportion of recycled rubber (RR) in the material rises, suggesting a decline in structural properties. The compressive strength, for instance, drops from 1.955 MPa in sample A-05 to 0.468 MPa in sample E-25, indicating that a larger rubber content reduces the concrete's resistance to applied stresses. The modulus of rupture, which decreases from 1.173 MPa (A-05) to 0.281 MPa (E-25), further reflects this, showing that the material becomes more likely to break under stress as the amount of rubber increases.

In addition to these declines in strength, the samples' bulk density also drops as the amount of recycled rubber increases. For A-05, the bulk density is 0.979 g/cm³, but for E-25, it drops to 0.689 g/cm³. As additional recycled rubber is added, the material's density appears to decrease, perhaps improving its thermal insulation qualities. Materials with a lower density tend to trap more air, which lessens heat transmission, making them generally better insulators. Although there is some variation in the moisture content across the samples (between 5% and 7%), there is no discernible relationship between the variations in mechanical or density characteristics. This implies that the influence of the recycled rubber content on overall performance is greater than that of the moisture content.

All things considered, adding recycled rubber to AAC lowers its density while decreasing its strength and stiffness, which may be advantageous for insulation purposes. For non-structural applications where insulation is the main issue, such as in energy-efficient building materials, AAC with a greater recycled rubber component (like E-25) is more appropriate due to its lower weight and potential for better thermal insulation. Nevertheless, more research on these materials' thermal conductivity and long-term durability would be required to properly evaluate their appropriateness for insulation.

By encouraging the use of sustainable building materials, this strategy supports a number of Sustainable Development Goals (SDGs), hence SDG 9: Industry, Innovation, and Infrastructure. AAC supports SDG 12: Responsible Consumption and Production by using recycled rubber, which helps to reduce waste and the environmental effects of production processes. Furthermore, as lightweight and energy-efficient materials like AAC with recycled rubber may help lower building energy consumption overall and carbon footprints, their use promotes SDG 13: Climate Action.

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