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The Effects of Direct Fire and Strength on Autoclaved Aerated Concrete Containing Semiconductor Electronic Molding Resin Waste (AAC-SEMRW) on Partition Panel Application

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ABSTRACT

The research highlights semiconductor electronic molding resin waste (SEMRW) has the potential to improve the strength and fire resistance of Autoclaved Aerated Concrete (AAC) due to its excellent properties of (SEMRW) in terms of physical, mechanical, and fire resistance performances. The possibility of SEMRW by its addition in AAC concrete is explored by analyzing the effect of varying additions on the properties of AAC. This fundamental research is to propose a different percentages composition (5%, 10%, 15%,20%, 25%, and 30%) of SEMRW as a partial replacement of sand and containing with standard amounts of cement, quartz sand, water, and a 1% aluminum paste. All specimens experienced a steam curing process for 12 hours at a temperature of 180°C and a steam pressure of 13 bar in an autoclave machine to produce (AAC- SEMRW). The results revealed 20% SEMRW of AAC provides the higher compressive strength at 5.19 MPa. Modulus young and Modulus rupture at 0.11 Gpa and 3.11 Mpa, respectively. In terms of the rate of direct fire analysis, the test gives a higher percentage at 90%. The findings show that AAC-SEMRW can be used as an eco-friendly alternative to typical construction materials by recycling industrial waste and decreasing environmental impact, hence promoting sustainable construction practices. These findings highlight the material's potential in applications that require lightweight, robust, and fire-resistant building solutions, hence contributing to future advances in green construction technology.

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1. Introduction

Currently, the replacement and reduction of the use of natural materials in particular, seeking to make use of waste, will satisfy the demand for developing construction materials in the future, contributing to the protection of the environment and natural resources. The necessity to address environmental problems associated to replacing natural sand with sustainable alternatives that do not degrade the performance of autoclaved aerated concrete (AAC) has led to a major increase in interest in this topic in recent years. The influence of sand replacements, such as compressive strength and fire resistance tests, has been the main focus of these studies. Among these efforts, the use of industrial waste as a secondary raw material in construction applications has significant interest. One promising involves semiconductor electronics materials containing resin waste into autoclaved aerated concrete (AAC) for partition panel applications [1]. In order to enhance energy efficiency in buildings, lightweight construction materials with low thermal conductivity, good strength, and high heat resistance are frequently used. Among these, autoclaved aerated concrete (AAC) is a popular alternative due to its superior thermal insulation and environmental benefits. AAC is noticeably lighter than ordinary concrete and provides improved heat resistance, lower thermal conductivity, minimum shrinkage, and faster building times. AAC is considered a sustainable and eco-friendly building material due to its capacity to reduce building energy consumption by roughly 50% without the need for extra thermal insulation layers on walls [2]. The material's eco-friendly nature is further enhanced by its ability to incorporate industrial waste products such as fly ash study by Baspinar *et al.,* 2014 [4], red mud study by Song *et al.,* 2022 [5], Ali *et al.,* 2021 research about rice husk waste [6], glass gypsum waste stated by Izzati Manaf *et al.,* 2022 [7] and graphite study by Peng *et al.,* 2020 [8], this results in lower energy use and a large environmental footprint.

The use of resin waste sand in AAC aids in the effective recycling of industrial waste while also improving the physical qualities of concrete such as compressive strength, young modulus, modulus of rupture, and density performance. Previous research revealed the potential benefits of employing resin waste in concrete mixtures, with positive results in terms of material performance and environmental effect [9]. Semiconductor electronic moulding resin waste (SEMRW), a byproduct of the semiconductor electronics manufacturing industry, is usually constituted of high-performance polymer polymers that display great strength, thermal stability, and chemical resistance [10]. Previous research has looked into the influence of adding various types of waste materials to AAC, with a particular emphasis on reducing porosity while keeping the material lightweight. Yusrianto *et al.,* (2024) did a study on the influence of polymeric resin waste on the microstructure of AAC and discovered that the waste particles assisted to decrease the porosity of the material [12]. Raj *et al.,* (2020) explored the use of resin waste to improve the durability and structural performance of AAC, concluding that adding resin waste might increase the material's density while retaining its lightweight properties. This balance between density and porosity is vital in applications such as partition panels, where mechanical strength is an important factor [13]. In comparison to conventional AAC, Manaf *et al.,* (2020) showed that AAC containing resin waste had greater compressive strength values, with the waste particles strengthening the material's interior structure. This is especially important for partition panels, because the compressive strength affects the stability and durability of the structure.

These studies have primarily focused on the impact of sand replacements such as compressive strength and direct fire analysis. The interaction between the cementitious matrix and the resin waste particles is the mechanism underlying this increase in compressive strength [14]. The ability of AAC with SEMRW to function at high temperatures is another important factor. AAC is frequently utilised in building partition panels when thermal stability and fire resistance are important factors.

In comparison to conventional AAC, Lalitha (2022) investigated the thermal performance of AAC using resin waste and discovered that the material demonstrated enhanced fire resistance. Because of the resin waste's excellent thermal stability, the material can withstand high temperatures without losing its structural perfomance, which makes it appropriate for uses where fire resistance is important. By adding SEMRW to AAC, its compressive strength and residual strength after exposure to high temperatures are both increased [15].

Noshin *et al.,* (2023) investigated the use of quarry dust in place of sand and found that while the compressive strength was similar to that of ordinary concrete at 2.5 MPa, strength decreased when more sand was substituted. For instance, the compressive strength decreased to 2.0 MPa at 50% replacement. Because it had a detrimental effect on the mix's workability and compaction, the uneven particle size distribution of the quarry dust was found to be one of the factors contributing to the strength loss [16]. The use of different proportions of glass waste (10%, 20%, and 30%) in AAC was investigated by Salahaddin *et al.,* (2022). While 10% replacement did not significantly improve compressive strength over the control, 20% and 30% replacement increased compressive strength (4.2 MPa and 4.5 MPa, respectively). As the glass content rose, porosity dropped, with the 30% replacement exhibiting the lowest porosity at 16%. The density stayed between 550 and 590 kg/m³. The 30% glass AAC shown exceptional heat resistance by retaining 80% of its initial strength after being exposed to high temperatures [18]. It is believed that the resin waste in this investigation contributed similarly to the samples' increased compressive strength. A suitable quantity of resin waste can increase the strength of concrete, claim Wenze *et al.,* (2023).

Nevertheless, a reduction in compressive strength was stated when the resin waste percentage rose from 25% to 30%, even though the strength was still roughly 32.3% more than that of the control sample at 25% resin waste content [19]. Dwarampudi *et al.,* (2021) studied the performance of AAC with different percentages of fly ash (15%, 25%, and 35%) as a sand replacement. The 15% and 25% fly ash AAC improved compressive strength (4.1 MPa and 3.9 MPa, respectively), however the 35% replacement resulted in a loss in strength (3.2 MPa), most likely because to the considerable fly ash content weakening the matrix. The density declined with increasing fly ash concentration, with 35% replacement indicating a density of 510 kg/m³, compared to 560 kg/m³ for the control [20]. Porosity also increased slightly at increasing fly ash percentages, reducing strength. Xusheng *et al.,* (2024) evaluated the impacts of replacing 20% fly ash for sand in AAC. Their findings showed that after 28 days of autoclave curing, the inclusion of fly ash increased the compressive strength of AAC from 3.5 MPa (control) to 4.2 MPa [21]. The greater strength was due to the pozzolanic interaction between fly ash and calcium hydroxide in cement, which resulted in the creation of more calcium silicate hydrates (C-S-H). The density of fly ash AAC decreased slightly from 550 kg/m³ to 530 kg/m³, demonstrating its lightweight nature. Porosity dropped from 21% to 18%, contributing to enhanced compressive strength and lowering the material's permeability [22].

2. Methodology

2.1 Preparation of AAC-SEMRW sample

STMicroelectronics Sdn Bhd, located in Johor's Muar Industrial Area, generates semiconductor electronic moulding resin waste (SEMRW). The waste was crushed into granules in the Concrete Technology Workshop, UTHM Pagoh, using a Fritsch Planetary Mono Mill Pulverisette 6 Classic Line from Germany. The resin waste was sieved according to the British Standard Specification for Test Sieves (BS 410) using Cooper Technology's Sieve Shaker. Figure 1 illustrates the usage of sieves with 0.6 mm apertures to achieve the desired particle size of 0.6 ± 0.05mm. Other resin waste sieve sizes were not considered in subsequent production phases or examinations.

Fig. 1. Material preparation (a) Resin waste (RW) from IC packages electronic industry; (b) Grinder Machine Fritsch's Planetary Mono Mill Pulverisette 6 Classic Line (c) Grinded resin waste

The raw components for each sample were weighed according to the mixing proportions shown in Table 1. The measurement errors for powder materials and water were within ±0.1g, while aluminium powder was within ±0.02g. For example, in sample F, the ingredients were mixed in the following proportions: 40% sand, 30% SEMRW, 7% lime, 23% cement, and 0.65% water. These ingredients were combined for about 15 minutes with an Allefix 2100W Electric Mixer. Then, Al powder (0.1%) was added and mixed for another 15 seconds to create a slurry. The slurry was poured into a mould until it was two-thirds full, then gently shook to allow air bubbles to float to the surface. The reaction took around 30 minutes, allowing the slurry to expand and completely fill the mould in. This procedure was performed for samples coded CS through E as shown in Figure 2. The slurry was then pre-cured at ambient temperature for 2 hours before being hydrothermally cured in an autoclave at 200°C and 13 bar pressure for 12 hours.

Table 1
The Different Composition of AAC-SEMRW as sand replacement

Sample Number	Sample of different ratio	Sand		Lime (%)	Cement (%)	Aluminum Paste (%)	Water (%)
		Sand (%)	SEMRW (%)				
CS-0	Control Sample (CS)	70.00	0.00	7	23	0.1	0.65
A-05	Sample A5_SEMRW_5	65.00	5.00	7	23	0.1	0.65
B-10	Sample B_SEMRW_10	60.00	10.00	7	23	0.1	0.65
C-15	Sample C_SEMRW_15	55.00	15.00	7	23	0.1	0.65
D-20	Sample D_SEMRW_20	50.00	20.00	7	23	0.1	0.65
E-25	Sample E_SEMRW_25	45.00	25.00	7	23	0.1	0.65
F-30	Sample F_SEMRW_30	40.00	30.00	7	23	0.1	0.65

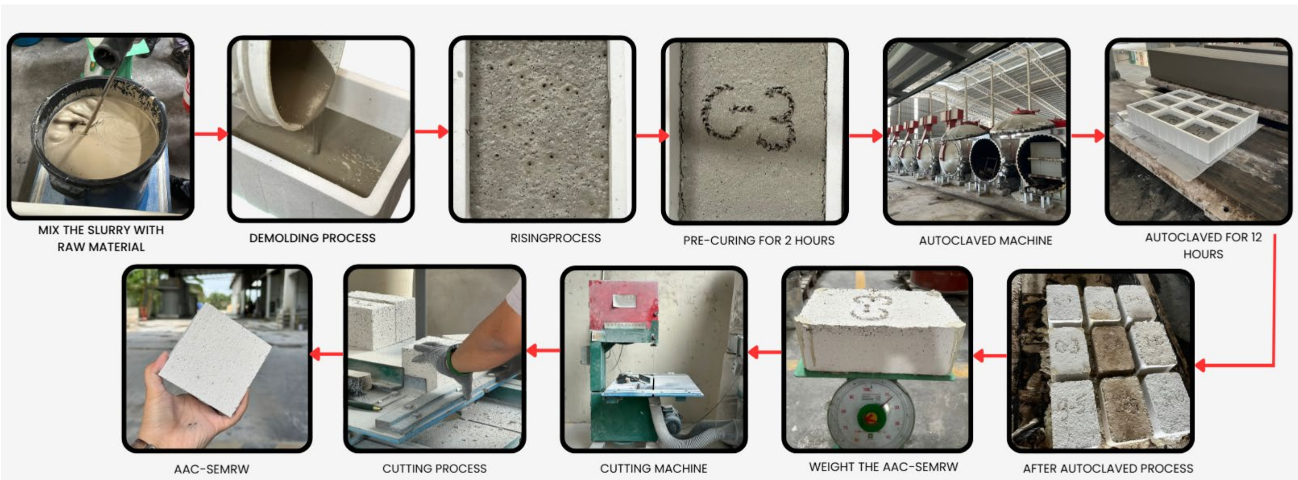

Fig. 2. Fabrication of AAC – SEMRW

2.2 Process of Testing Sample of AAC-SEMRW
2.2.1 Compressive strength test

The specimen under examination, labeled AAC-SEMRW, was prepared in a cubic form with precise dimensions of 100 mm × 100 mm × 100 mm. This particular size allows for standardized testing and reliable results. The testing was carried out using a Controls' Automax Pro Compact-Line, Super-Automatic EN Tester, specifically designed for compressive strength testing of concrete specimens such as cubes, cylinders, and blocks. This device, model 50-C56F02 from Italy, includes a computerized control console and Data Manager software, which ensure precise and automated handling of test parameters. The testing was conducted in Kim Hoe Thye Industries Sdn. Bhd. For this specific test, the (BS EN 12390-3) was followed, which is the standard procedure for determining the compressive strength of hardened concrete specimens. Figure 3 in the documentation illustrates the setup, providing a visual reference for the equipment used and the testing environment. The use of automated, computer-controlled equipment enhances the accuracy of the data collected, ensuring that the results reflect the true compressive strength of the sample.

Fig. 3. Compressive strength test instrument

Before testing, several safety and preparatory steps were followed: confirming the compression machine was functional, wearing safety gloves and goggles, and recording each sample's dimensions (in mm) and mass (in kg). After these preparations, the machine was powered on, and the sample was placed at the center of the loading area. Sample details were entered in the 'Report' tab, and test settings were verified in the 'Graph' tab under the 'Settings' icon. Selecting the 'Run' icon initiated the test, lowering the piston until it contacted the top of the sample. A load rate of 0.7 MPa/s was applied for up to 60 seconds. If the sample began to crack, the load stopped automatically; otherwise, it ceased after 60 seconds. The maximum load applied (displayed in MPa) was recorded. Once the piston returned to its starting position, the broken sample was removed and the machine was cleaned. The recorded data was cross-checked to ensure accuracy with the displayed result. Eq. (1) was used to obtain compressive strength and Eq. (2) was used to obtain and calculate the Young's modulus.

$$F = \frac{P}{A} \tag{2}$$

$$E = (\frac{F}{A})/(\frac{\Delta_L}{L}) \tag{2}$$

2.2.2 Direct fire analysis

For this test, the direct fire for AAC-SEMRW was conduct by using ASTM E-119 to determine the ability to witstand exposure to fire at Kim Hoe Thye Industries Sdn. Bhd. Preparing 100x100x100 mm cube samples of AAC-SEMRW in six different mix ratios. During the direct fire analysis, key parameter such as temperature, duration of exposure and visual change. The sample was carefully monitored and recorded. The sample was place 40cm far from the fire source and heated for 5 minutes at 500℃ to 600℃. Figure 4 shows the sample before, during, and after direct fire for 5 minutes. The weight loss recorded for each sample served as an indicator of material degradation, and the reflecting rate of mass was lost due to exposure to heat and combustion effects. By analyzing weight loss across different ratios, the test provided insights into which compositions retained structural properties better under fire conditions, helping to optimize the AAC-SEMRW formula for enhanced fire resistance in building applications.

$$Rate\ of\ Direct\ Fire = \frac{Exposed,\ T1 - unexposed,\ T2}{Exposed,\ T1}\ x\ 100 \tag{3}$$

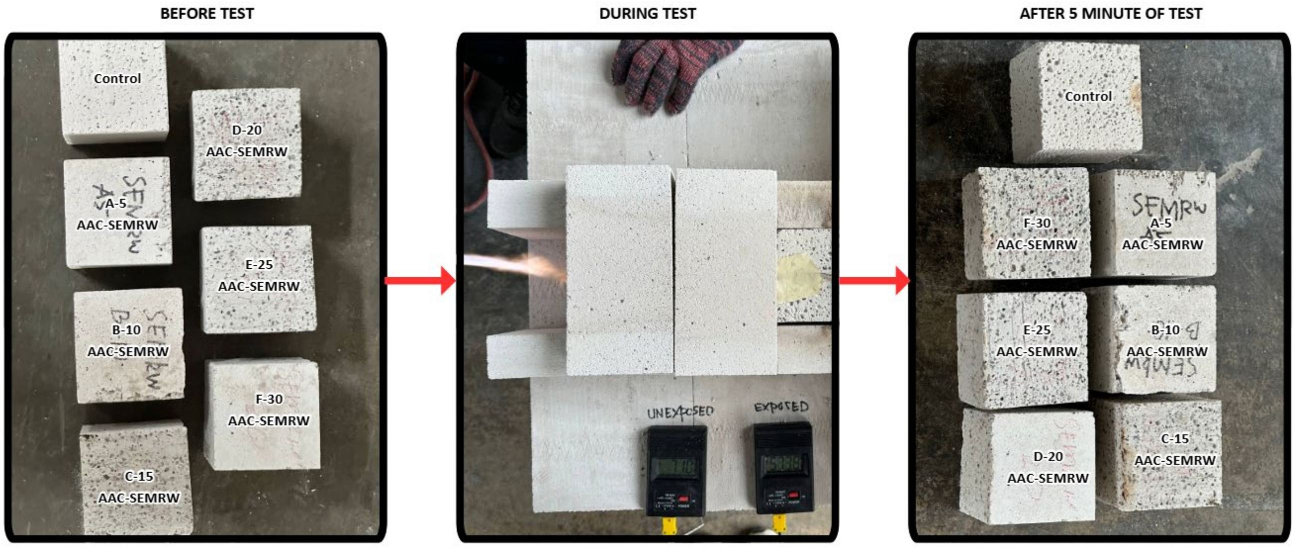

Fig. 4. The direct fire of AAC-SEMRW with different proportion after testing

3. Results

3.1 Compressive Strength

The AAC-SEMRW 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 SEMRW content. With the appropriate composition, SEMRW 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 SEMRW contents

Sample Number	Compressive Strength (MPa)	Modulus Young (GPa)	Modulus Rupture (MPa)
CS-0	2.64	0.06	1.45
A-05	4.06	0.10	2.46
B-10	4.44	0.12	2.13
C-15	5.06	0.10	3.04
D-20	5.19	0.11	3.11
E-25	4.75	0.09	2.85
F-30	3.20	0.04	1.92

The compressive strength of AAC at different SEMRW concentrations is displayed in Figure 5. The data indicates that the compressive strength rises from 4.06 MPa at 5% SEMRW to 5.19 MPa at 20% SEMRW as the SEMRW content increases. At 20% SEMRW, the highest compressive strength of 5.19 MPa was recorded. According to Tural *et al.,* (2024), a higher percentage of silica, alumina, and calcium oxide are responsible for pozzolanic reactivity and cementitious properties AAC with 20% by weight of SEMRW was determined to be the ideal sample [23]. With the exception of the 30% SEMRW sample, all SEMRW samples satisfied the grade-4 standards based on their compressive strength ratings. ASTM C1693, the physical specifications for AAC, states that AAC having a compressive strength between 4.0 and 6.0 MPa is considered "AAC grade-4." According to research by Rajkohila *et al.,* (2024), the AAC based on fibre as addition and compressive strength were increased by 12.67% and 15.12%, respectively, in comparison to the control sample [25]. Furthermore, it has been demonstrated that pozzolanic compounds enhance the Portland cement binder's long-term strength via pozzolanic reactions. Pozzolanic material's beneficial effects on compressive strength of aerated concrete and AAC has been investigated in the literature [26].

It is believed that the resin waste in this investigation contributed similarly to the samples' increased compressive strength. A suitable quantity of resin waste can increase the strength of concrete, claim Wenze *et al.,* (2023). Nevertheless, a reduction in compressive strength was stated when the resin waste percentage increased from 25% to 30%, even though the strength was still roughly 4.75 MPa for E-25 and 3.20 MPa for F-30 more than that of the control sample at 2.64MPa resin waste content [27]. According to Shaofeng *et al.,* (2022), this strength decrease may be the result of unreacted silica caused by an inadequate amount of calcium hydroxide that forms during cement hydration. The significant amount of resin waste may potentially be the reason of the decrease in AAC's compressive strength since it may leave some silica unreacted [28]. By reusing SEMRW, an electronics industry byproduct, into AAC manufacture, this approach helps to reduce waste and encourages sustainable construction. The use of industrial byproducts like SEMRW decreases reliance on traditional raw materials like silica and alumina, which helps to conserve natural resources. Furthermore, this strategy reduces the amount of electronic waste that ends up in landfills, lowering the environmental impact and potential soil and water pollution. The pozzolanic reactivity of SEMRW improves the cementitious characteristics of AAC, reducing the requirement for extra Portland cement and thereby lowering carbon dioxide emissions connected with cement manufacture. As a result, incorporating SEMRW into AAC manufacture not only increases material performance but also adheres to circular economy concepts, promoting more environmentally friendly and resource-efficient construction techniques.

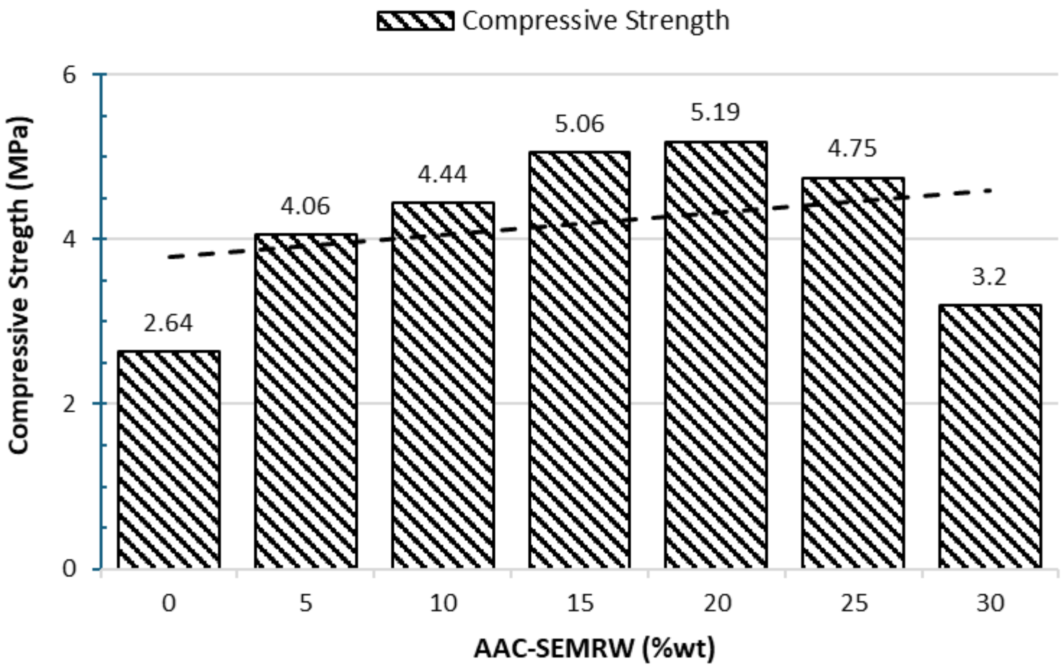

Fig. 5. The compressive strength of AAC with different SEMRW contents

3.2 Modulus Young & Modulus Rupture Analysis

Figure 6 demonstrates the Young's modulus and modulus of rupture for fresh AAC with various SEMRW concentrations. The findings for Young's modulus are consistent with the compressive strength results, with a linear increase in Young's modulus as compressive strength increases. Young's modulus rises with compressive strength, up to a maximum of 10% by weight. The results show a clear linear link between Young's modulus and compressive strength. Furthermore, there is a scarcity of published research and data on the Young's modulus of AAC. Concrete's heterogeneous composition and density have a direct impact on compressive strength and Young's modulus. When additional SEMRW % was introduced, the Young's Modulus increased and decrease based on the percent of SEMRW added. Increasing the percentage of SEMRW as a filler led to higher density [30]. Other studies, such as Poongodi and Murthi (2021), have shown a relationship between Young's modulus and compressive strength in lightweight concrete. Their studies revealed that Young's modulus grows linearly with the compressive strength of lightweight concrete [31]. Figure 4 shows that, similar to Young's modulus, the modulus of rupture has a linear relationship with compressive strength. This linear relationship occurs when the modulus of rupture is stated as a function of compressive strength. The modulus of rupture, also known as flexural strength, tensile strength, or bending strength, is used to determine a material's strength before failure. The modulus of rupture increase with greater SEMRW concentration, although only by 20% by weight. The maximum rupture modulus was 3.11 MPa with a SEMRW concentration of 20%. This peak value coincided with the samples' maximum compressive strength and Young's modulus readings.

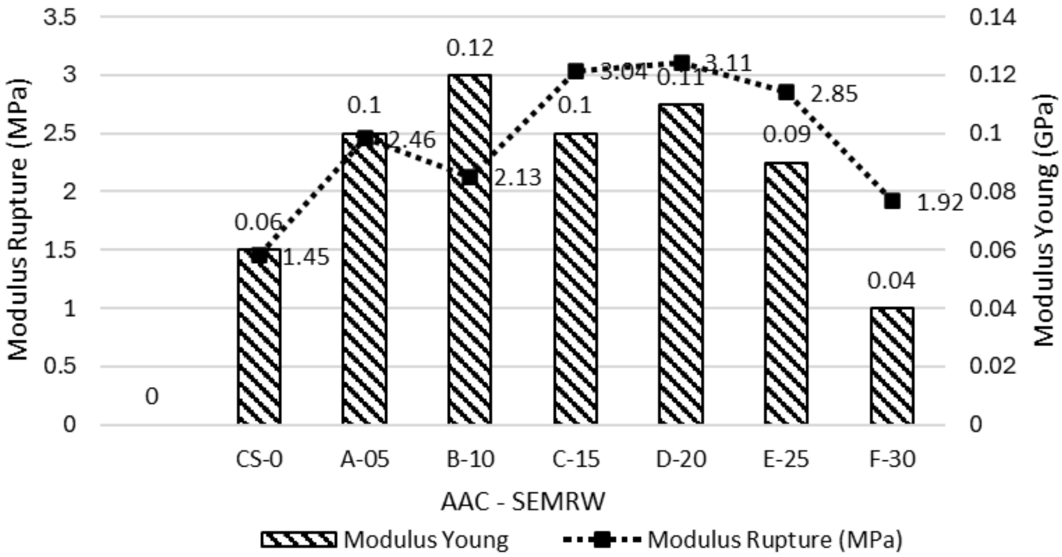

Fig. 6. The correlation between the modulus Young and modulus of rupture with compressive strength of AAC versus different SEMRW contents

3.3 Direct Fire Analysis AAC-SEMRW

Table 3 state the value of exposed, unexposed and rate of direct fire of AAC-SEMRW based on direct fire analysis. All samples did not exhibit usual colour behaviour, such as black, after being exposed to direct fire at temperatures ranging from 500℃ to 600℃ for 5 minutes. The sample turned black because the fire temperature was less than 600℃. Lam *et al.,* (2020) compared the direct fire of high performance self-consolidating concrete and normal strength vibrated concrete at a maximum direct fire temperature of 520 ℃ for 300 seconds [32]. Although being subjected to a direct fire at 500 ℃ for 5 minutes, the samples' physical surface remained free of cracks and did not burn too hard, as visible to the naked eye. Furthermore, the AAC-SEMRW sample does not melt when exposed to direct fire at 500 ℃ for 5 minutes because the combination of SEMRW in AAC blends very well and does not burn or crack. This conclusion contradicts prior research by Reena Dewi *et al.,* (2022), who investigated eco-friendly concrete containing recycled plastic as a partial replacement for sand. The analysis found that the sample had an anomalous colour (black) and cracked and burned with direct fire at temperatures below 1000 ℃ for 300 seconds [33].

Table 3
The compressive strength, specific strength, modulus Young and modulus of rupture of AAC with different SEMRW contents

Sample Number	Temperature AAC - SEMRW		Rate of direct fire (%)
	Exposed Surface (°C)	Unexposed surface (°C)	
CS-0	288.6	32.5	88.7
A-05	126.5	34.3	72.0
B-10	170.6	35.6	79.1
C-15	346.0	36.5	89.5
D-20	355.6	35.8	90.0
E-25	293.3	36.8	87.5
F-30	284.0	36.3	87.0

The surface study of AAC-SEMRW following direct fire testing at 500 ℃ for 5 minutes reveals a considerable improvement in fire resistance qualities, especially for the sample containing 20% SEMRW. Among the studied samples, the 20% AAC-SEMRW specimen shows minimum surface damage, with no obvious cracks or traces of burning. This result implies that the addition of 20% SEMRW improves the material's resistance to high temperatures. The 20% SEMRW concentration appears to strike the right balance, preserving the characteristics of AAC while improving thermal resistance. Futhermore, 20% SEMRW is an optimal fraction for providing both direct fire and durability in AAC applications. This makes 20% AAC-SEMRW an appropriate choice for applications that require direct fire analysis as noted in Figure 7. The use of SEMRW as a partial substitute in AAC decreases reliance on traditional raw materials like sand, minimising the environmental impact of mining and processing. Furthermore, the higher direct fire analysis of AAC-SEMRW extend the material's lifespan, lowering the need for repairs or replacements and thereby reducing construction waste over time. These eco-friendly properties make AAC-SEMRW a long-term solution for building applications, harmonising with green construction standards and contributing to the reduction of greenhouse gas emissions in the construction industry.

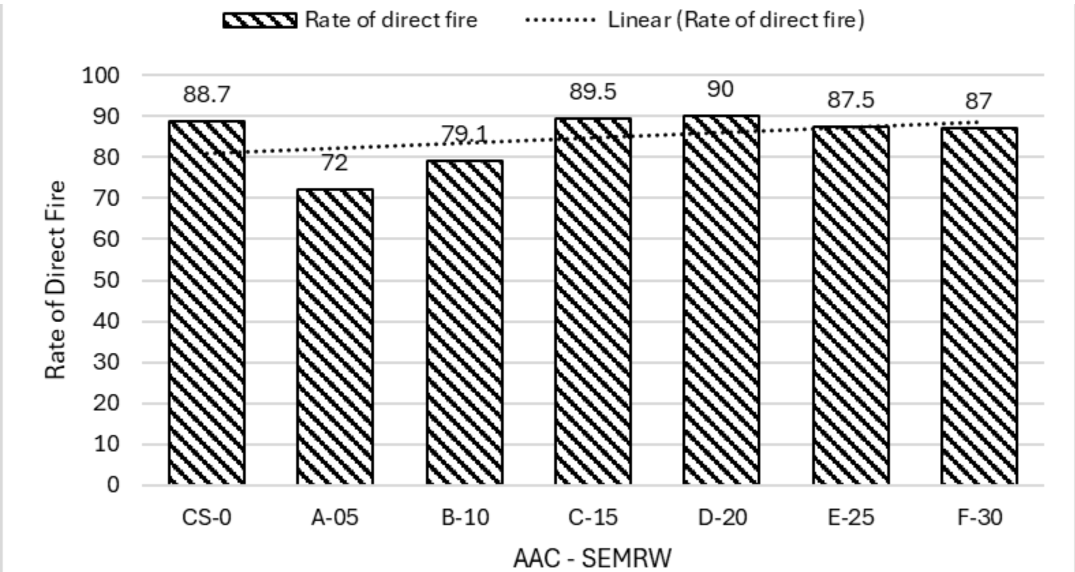

Fig. 7. Rate of direct fire analysis data

4. Conclusions

This study investigated the impact of semiconductor electronic moulding resin waste (SEMRW) on the characteristics of autoclaved aerated concrete (AAC). The results showed a positive association between SEMRW content and AAC compressive strength, with values ranging from 4.06 MPa at 5% SEMRW to 5.19 MPa at 20% SEMRW. This modification results in a significant increase, establishing 20% SEMRW as the optimal composition for maximising compressive strength. Interestingly, all SEMRW-containing samples matched the ASTM C1693 standards for AAC grade-4, with the exception of the sample containing 30% SEMRW, which had a weaker strength of 3.20 MPa. The material features of the resin waste contributed to the increase in compressive strength, which is consistent with prior research that highlighted the significance of pozzolanic materials in improving AAC durability and mechanical properties. The results also showed that increasing the SEMRW concentration by up to 15% improved the modulus of rupture, which peaked at 3.11 MPa at 20% SEMRW. Furthermore, the Young's modulus and modulus of rupture analyses showed a linear relationship with compressive strength, highlighting the interdependence of these mechanical parameters. Based on the direct fire analysis of AAC-SEMRW, the specimen with 20% SEMRW demonstrated the highest resistance to direct fire, making it an optimal material for insulation applications. When exposed to 500°C for 5 minutes, it showed no visible cracks or signs of burning. This indicates that incorporating 20% SEMRW significantly enhances the material's resilience to high temperatures and thermal stress. The insulating properties of SEMRW notably improve AAC's fire resistance, positioning it as an excellent alternative for applications requiring superior thermal stability.

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