PROGRESS IN ENGINEERING APPLICATION AND TECHNOLOGY
e-ISSN: 2773-5303

PEAT

Vol. 6 No. 1 (2025) p. 355-362
https://publisher.uthm.edu.my/periodicals/index.php/peat

Compressive Strength and Porosity Characteristics of Geopolymer Concrete Containing Used Tyre as Artificial Aggregate

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DOI: https://doi.org/10.30880/peat.2025.06.01.038

Article Info

Received: 19 January 2025
Accepted: 02 February 2025
Available online: 30 April 2025

Keywords

Crumb rubber, geopolymer concrete, compressive strength

Abstract

The accumulation of waste rubber, particularly from discarded tyres, poses a serious environmental challenge. Its non-biodegradable nature contributes to pollution and disrupts natural habitats. Current mitigation methods, including incineration and landfilling, have significant limitations such as greenhouse gas emissions and the need for extensive land use. To address this issue, utilizing waste rubber as a replacement material in geopolymer concrete offers a promising and innovative solution. This study focused on assessing the feasibility of incorporating crumb rubber as a partial replacement for fine aggregates in geopolymer concrete. The primary objectives were to evaluate the workability, density, and compressive strength of geopolymer concrete containing different proportions of waste rubber from 0-40 %. The crumb rubber, with particle sizes ranging from 1 millimeter to 5 millimeters, was sourced from Parit Sulong, Malaysia, while fly ash from the Manjung Coal-Based Thermal Power Plant was used as the main binder component. Laboratory tests conducted included the Slump Test, Density, Compressive Strength, and Elevated Temperature tests on cube specimens measuring 100 millimeters by 100 millimeters by 100 millimeters after curing periods of 7, 28, and 56 days. The results showed that increasing rubber content improved the workability of the concrete due to enhanced flowability. However, this improvement was accompanied by reductions in both density and compressive strength. While the reduced strength limits the suitability of rubberized concrete for structural applications, its lightweight characteristics make it a viable option for non-structural uses such as lightweight or waterproof materials. This study highlights the potential of integrating waste rubber into sustainable construction practices and emphasizes the importance of further research to optimize the balance between performance and environmental benefits.

1. Introduction

Concrete is the most used construction material due to its durability, strong mechanical properties, ease of handling, versatility in forming various shapes, and variety of component materials. Geopolymer concrete is different from traditional concrete because it uses specific materials. This gives it unique properties that set it apart from regular concrete. Geopolymer concrete is an innovative construction material known for its unique properties and composition. Geopolymer concrete, a new type of building material first developed in 1990 [1], is seen as an alternative to cement-based concrete because it uses readily available raw materials and has good mechanical properties.

Production of geopolymer concrete requires less heat energy and has a lower carbon footprint than traditional Portland cement concrete [2], making geopolymer concrete an environmentally friendly construction material. Geopolymer binders offer several advantages, including high compressive strength, fire, and chemical resistance. Geopolymer made from fly ash and an alkaline activator solution, is commonly activated with sodium hydroxide and sodium silicate. Geopolymer concrete's environmental impact can reduced by using industrial byproducts as the primary binder, such as fly ash.

Rapid population growth and increased car use have led to a rise in solid waste disposal, such as used tyres that were remain in the environment for years. In road construction, many types of binding materials other than concrete, such as asphalt concrete or bitumen and lime for lime concrete [3]. The disposal of waste tyres, which are resistant to degradation, presents an environmental challenge. Recycle products made from used tyres are the most effective waste management method for construction. This strategy protects the environment by reducing pollution and preserving natural aggregate materials. Tyres have several 2 advantages, including low density, low ground pressure, long-term durability, and high compressibility. Tyre rubber is an effective substitute to deformable concrete due to its high strength and ability to withstand pressure [4].

The goal of this research is to investigate the effect of used tyres as an artificial aggregate on the workability of geopolymer concrete and to assess the compressive strength of geopolymer concrete containing used tyres. Therefore, the selecting of rubber crumb waste tyre as partial replacement of fine aggregate materials in concrete mix design is one of the alternative ways to save the environment. Since Malaysia construction industry is toward the sustainable construction and green path of construction, this study is significant to explore the performance of these combination in concrete.

2. Material and Method

2.1 Material

One of the source materials used in this investigation of geopolymer concrete was fly ash as show in the Fig. 1. It was gathered from Manjung Coal-Based Thermal Power Plant. As an alkaline activator, sodium silicate (Na2SiO3) is used in the geopolymer concrete process. This material goes by the names "water glass" and "liquid glass," respectively, because it can be found in both solid and liquid states. Alkaline activators like sodium hydroxide (NaOH) and sodium silicate are used to activate fly ash in geopolymer concrete.

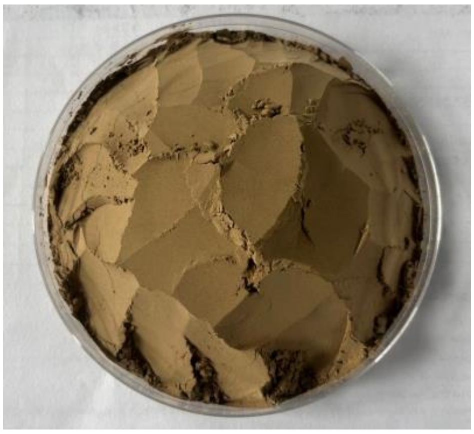
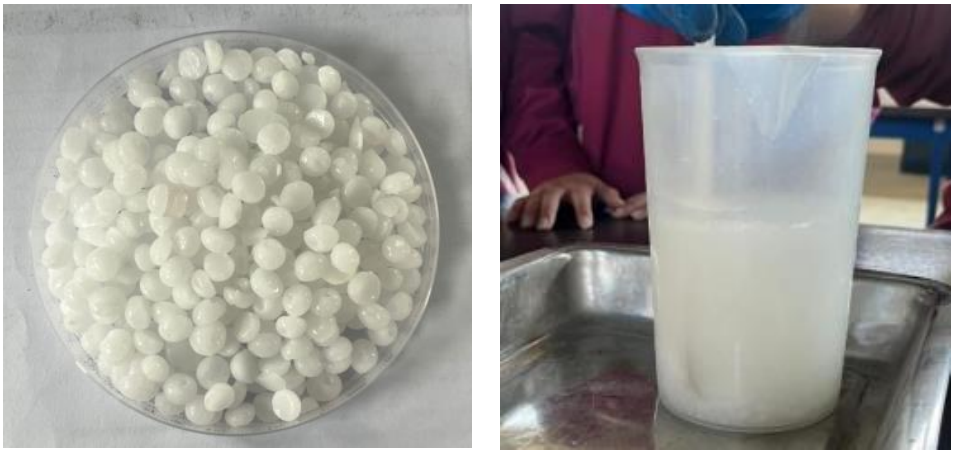


***Fig. 1**: The sample of fly ash.*

Sodium hydroxide as show in Fig 2, also known as alkali or caustic soda, is a strong inorganic compound, which is of wide use in a myriad of industrial and scientific activities. It comes in different forms, including powders, granules, or pre-prepared solutions of different strengths. For most of its applications, sodium hydroxide is used in the form of solid, white crystals. In the production of geopolymer concrete, it is usually mixed with sodium silicate to produce an alkaline activator. This mixture is efficient at speeding up chemical reactions in geopolymer although it yields a less fluid gel.



(a) (b)

Fig. 2: The sample of (a) sodium hydroxide and (b) sodim silicate

Used tyres, particularly those from trucks, are recycled to make crumb rubber, which is used as a partial substitute for fine particles in geopolymer concrete. The procedure begins with shredding tyres into 50-100 mm fragments. In the following stage, known as granulation or the secondary process, the rubber particles are reduced to sizes ranging from 0.6mm to 5mm. For this investigation, crumb rubber with a size range of 1mm to 5mm is used as shown in Fig. 3. Before incorporating the particles into the geopolymer concrete mix, they are sieved to guarantee size consistency.

Fig. 3: The sample of crumb rubber

Table 1**:** Detail of geopolymer concrete mix proportion (kg/m^3)

ID Mix Code	Rubber	Fine Aggregate	Fly Ash	Coarse Aggregate	NaOH	Na_2SiO_3	Extra Water
R0 + FA100	0	645	350	1200	41	103	35
R10 + FA90	64.5	580.5	350	1200	41	103	35
R20 + FA80	129	516	350	1200	41	103	35
R30 + FA70	193.5	451.5	350	1200	41	103	35
R40 + FA60	258	387	350	1200	41	103	35

Table 1 presents the mix proportions for various formulations of geopolymer concrete, focusing on the incorporation of rubber and fly ash as part of the aggregate composition.

2.2 Method

The process of making geopolymer concrete is like that of conventional concrete, however it does not include cement and requires less water. Begin by precisely weighing all the material and ensuring their dryness. Mix the dry materials, including both sizes of rubber aggregate, on a tray until fully combined. This guarantees a consistent distribution of the components. Proper preparation at this stage is critical to obtaining a consistent blend.

Mix sodium hydroxide and sodium silicate with water until the solution forms a slurry and cools to room temperature. Gradually incorporate the activator solution into the dry mix, adding more water as needed to obtain the desired workability. Because geopolymer concrete hardens fast, the mixing and casting process needs to be completed as soon as possible to avoid premature setting. Proper attention to these phases guarantees that the concrete reaches its intended strength and durability characteristics.

Specimens were prepared in the form of cubes with dimensions of 100 mm x 100 mm x 100 mm. Specimens were placed in an oven at 65 °C after 24 hours. All specimens were cured for 24 hours at room temperature before being placed in the oven Geopolymer concrete was covered with plastic before being placed in the oven for heating, as shown in Fig. 1, to avoid thermal shock, which helps minimize cracks in the concrete. After being removed from the oven, the specimens were cured at room temperature for 7 days, 28 days and 56 days. Meanwhile, for elevated temperature tests, all tests were performed after curing at room temperature after 28 days.

Fig. 4: The sample of geopolymer concrete covered with plastic to complete the curing in oven.

The total number of concrete samples prepared for testing was categorized based on curing age and exposure conditions. Specimens were prepared for three curing durations: 7, 28, and 56 days, with additional classifications based on exposure to different temperature conditions, including no oven heating, 100°C, and 200°C. For the 7-day curing period without oven heating, two specimens were prepared for each rubber content level (0%, 10%, 20%, 30%, and 40%), resulting in a total of ten samples. For the 28-day curing period without oven heating, three specimens were prepared for each rubber content level, resulting in fifteen samples, while the 56-day curing period without oven heating included two specimens per rubber content level, totaling ten samples.

3. Result And Discussion

3.1 Workability

Table 2 shows the workability of geopolymer concrete using crumb rubber as an artificial aggregate based on slump test results. The control specimens (0% rubber) have a slump value of 165 mm as how in Table 2, which represents the baseline workability. In contrast, when a specified percentage of aggregate is replaced with crumb rubber, the workability of geopolymer concrete gradually rises from 10% to 40% rubber content, with slump values ranging from 175 mm to 185 mm.

The use of crumb rubber improves the workability of the geopolymer concrete due to its lightweight and elastic qualities, which minimize internal friction in the mix. This pattern shows that crumb rubber increases the fluidity of the mix, making it simpler to handle and position. However, excessive workability might cause issues like as segregation or bleeding, especially at higher rubber percentages.

Despite this, geopolymer concrete mix designs remain acceptable because the slump test results surpass 150 mm, fulfilling the workability criteria for actual building applications. The geopolymer concrete mix technique remains simple and efficient, making it a suitable alternative for use in site applications that require increased workability. Further testing, especially compressive strength and increased temperature resistance, should be conducted to confirm that the mix performs optimally at varies rubber content levels.

***Table 2*: Result of slump test**

Rubber Percentage	Slump Value (mm)
0%	165
10%	175
20%	175
30%	180
40%	185

3.2 Density

The density test is carried out before to the compressive strength test. The density of concrete mixes is measured on three separate curing days using the mass per unit volume formula. Determining the dry density of concrete cubes is critical owing to differences in combination proportions, which might result in varied masses for each specimen.

The graph below represents density of concretes made with varied percentages of crumb rubber after curing for 7, 28, and 56 days. The curve on the x-axis represents the control batch and the batches with 10%, 20%, 30%, and 40% rubber in their mix, while the y-axis represents the density of fresh concrete in kg/m^3. To provide clarity, each bar is colour-coded: blue bars show density after 7 days, while orange-coloured bars represent the densities after 28 and 56 days.

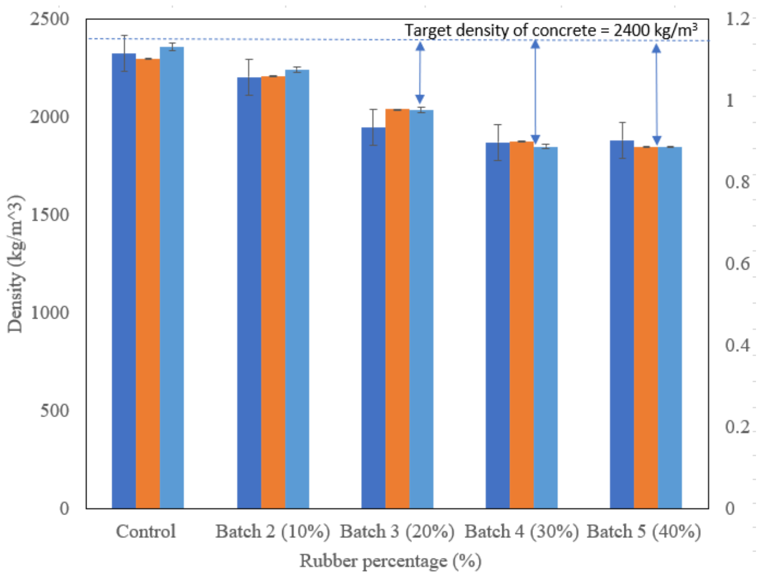


***Fig. 5*: Density of geopolymer concrete at 7, 28 and 56 days**

The graph in Fig.5 shows that the control batch with no rubber has a density of around 2400 kg/m^3, which is comparable to standard concrete. As with density, increasing the amount of rubber element causes it to decrease at higher percentages such as 30 and 40%, but its trend at different curing times, 7, 28, and 56 days, remains stable and steady.

Thus, as density, at longer-term curing, remains firm on account of these findings in place. Overall, the results indicate how the addition of crumb rubber changes the density of concrete and provides information for its possible use in cases where lightweight concrete is desirable. This would be useful information for engineers and academics trying to improve concrete formulations toward more sustainable construction methods.

3.3 Compressive Strength

This graph in Fig.6 shows the compressive strength behaviors of the material, depending on different percentages of rubber and curing times-7, 28, and 56 days-which indicates that with the increase in the content of rubber, the strength goes down consistently. The control group, without any rubber, shows the highest compressive strength for all curing times and is taken as the benchmark for performance.

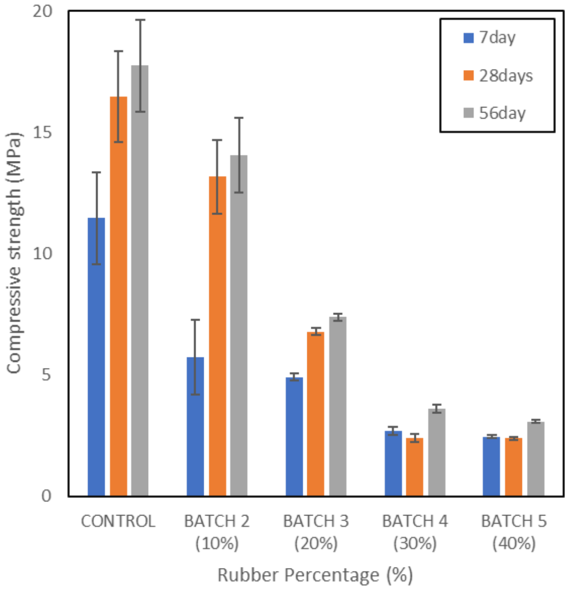


Fig. 6: Result of compressive strength.

Batch 5 with 40% rubber has the lowest compressive strength, indicating that the high rubber content has a significant negative impact on the material's resistance to compressive pressures. These data imply that increasing rubber content, while providing a few benefits like as improved flexibility or even environmental sustainability, significantly affects the compressive strength of the specimens.

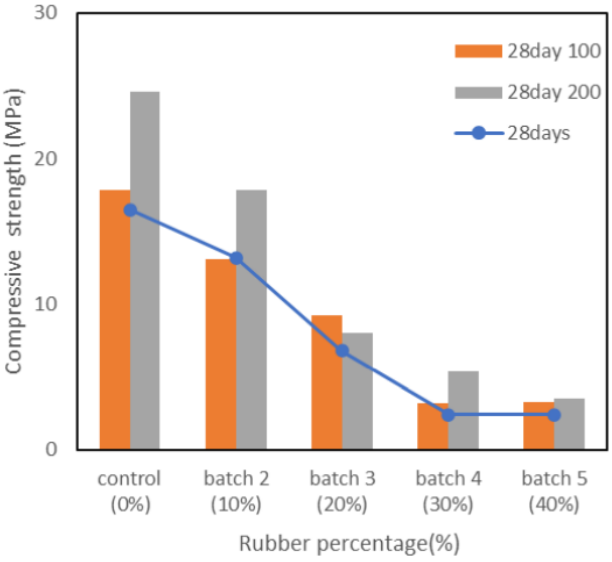


Fig. 7: Result of compressive strength with elevated temperature test

For concrete samples at 28 days, the data derived from the graphs demonstrates a detailed link between variations of the rubber content, curing temperature, and compressive strength. The control sample, which contains no rubber, has the greatest compressive strength values under all circumstances. Its values are 17.5 MPa, 25 MPa, and 16 MPa for curing at 100°C, 200°C, and room temperature, respectively. The increase strength at 200°C belongs to increased hydration reactions and density at high temperatures, whereas ambient curing has somewhat lower strength 58 due to slow hydration.

The compressive strength of Batch 2 (10% rubber) reduces to 13.5 MPa, 17.5 MPa, and 14 MPa under the identical circumstances, demonstrating the weakening impact of the rubber inclusion. While the drop is evident, curing at 200°C produces better strength, suggesting that the higher temperature of curing may more balance the reduction caused by rubber.

The findings in Fig. 7 demonstrate that compressive strength falls as rubber content increases. Higher curing temperatures (200°C) provide a benefit, particularly for lower rubber percentages, due to improved hydration and bonding. This benefit decreases with increasing concentration, indicating a limit to the compensating impact of high-temperature curing. These findings highlight the careful adjusting that were be necessary in terms of rubber % and curing conditions to balance sustainability and structural performance in rubberized concrete.

3.4 Water Absorption Rate

The relationship between rubber content, water absorption, and evaporation duration reveals important information about the material's porosity. It was shown that both water absorption and evaporation duration are inversely linked to rubber content, a trend that may be explained by rubber qualities, particularly its nature, which affects the material's interaction with water from the very core.

The graph in Fig.8 illustrates the relationship between the percentage of rubber content incorporated into the concrete mix and the corresponding water absorption rate measured in millilitres per hour (ml/h). The data indicates that water absorption increases significantly with higher percentages of rubber content in the concrete.

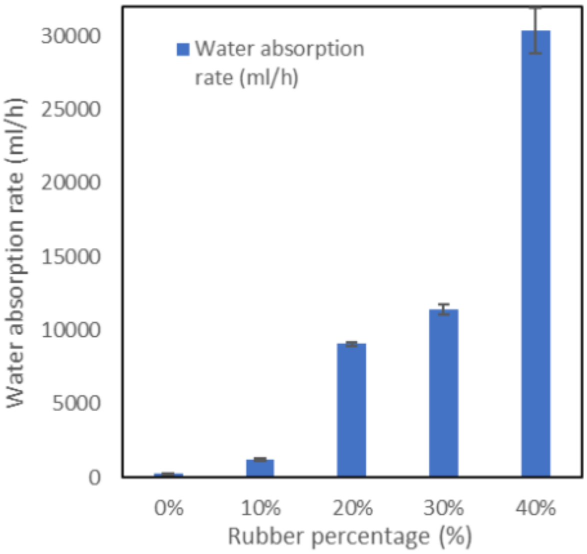


Fig. 8: Result of water absorption rate test.

This trend suggests that the inclusion of crumb rubber as an aggregate increases the porosity of the concrete matrix, leading to higher water absorption rates. The significant rise at higher rubber contents may be attributed to the lower bonding ability of rubber particles with other concrete components, which creates micro voids and pathways for water penetration.

In conclusion, the study demonstrates that the rubber content in geopolymer concrete plays a crucial role in determining the material's porosity, which significantly affects its water absorption and evaporation characteristics. Higher rubber content leads to increased porosity, resulting in poorer moisture capacities that can compromise the durability and structural integrity of the concrete [5]. Therefore, future 60 research should prioritize optimizing rubber content to enhance performance metrics for various applications, addressing specific environmental challenges and user needs. This optimization was contributed to the development of sustainable construction materials that effectively balance performance and ecological considerations.

4. Conclusion

The objectives of this paper were met by studying the workability, compressive strength, and density of geopolymer concrete containing used tyre rubber as a source of artificial aggregate. The findings reveal that the addition of crumb rubber significantly improved the workability of geopolymer concrete, as evidenced by the increasing slump values with higher rubber content. This is because the rubber serves as an additive, enhancing the flow and workability of the concrete mixture. This trend suggests that incorporating used tyre rubber increases the mix's flowability, which is advantageous for permeable pavements such as pedestrian walkways.

These results conclude the completion of the first objective of this study. Furthermore, the compressive strength in the investigation decreased steadily with increasing rubber content, reaching a minimum at 40% rubber. This decline is attributed to the poorer bond between the rubber and other concrete components. Similarly, the density decreased as the rubber content increased, which could be advantageous for lightweight concrete applications. While rubber improves workability, it negatively impacts compressive strength and density, which is a critical consideration for structural applications.

These findings conclude the completion of the second objective of this study. In summary, adding rubber to geopolymer concrete enhances properties such as workability while reducing density and significantly decreasing compressive strength. This finding supports the use of rubber in concretes for non-structural purposes where lightweight, waterproof, or highly flowable materials are required. Further research and optimization are necessary to balance the benefits of incorporating rubber with its effects on strength and durability to make this material widely acceptable. The author would also like to thank the Faculty of Engineering Technology, Universiti Tun Hussein Onn Malaysia for its support.

Acknowledgement

This project paper is supported by the Universiti Tun Hussein Onn Malaysia. The author would like to thank the Faculty of Engineering Technology, Universiti Tun Hussein Onn Malaysia for providing the necessary research facilityfor this study.

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