APPLIED MATERIALS AND TECHNOLOGY
Jamt.ejournal.unri.ac.id

Research Article

Properties of concrete containing crumb rubber and rice husk ash mixing with peat water

Habib Abdurrahman[1], Nur Alfikri[3], Arief Rijaldo[4], Mia Qoryati[5], Horas Saut Maringan Marpaung[2], Gunawan Wibisono[2], Monita Olivia[2,*]

ABSTRACT: This study compares the effects of peat water and normal water as mixing and curing water on the properties of crumb rubber and rice husk ash concrete (CR-RHA). The number of crumb rubber and rice husk ash used on the concrete followed the optimum mixture from a previous study, which was 5% and 10%, respectively. The crumb rubber was treated to overcome the lack of adhesion by soaking it in water for 24 hours. Normal concrete (PCC) was also cast as a control. CR-RHA and PCC concrete were mixed and cured using normal and peat water. Compressive strength, tensile strength, and porosity were tested at 3, 7, 14, 28, and 56 days. In general, CR-RHA concrete and PCC concrete showed lower performance when mixed and cured with peat water compared to normal water. Peat water with high acidity decreased the calcium content and developed the amount of pores in concrete, resulting in strength reduction. However, due to the excess pozzolan from rice husk ash, CR-RHA concrete had better resistance as the strength loss was relatively smaller, respectively 11.4% at 28 days and 10.6% at 56 days. Furthermore, CR-RHA concrete showed lower porosity, higher compressive strength, and tensile strength than PCC concrete due to rice husk ash that improved concrete density by generating CSH and crumb rubber that prevented concrete from spalling in an acidic environment. It was also found that compared to the previous study, pre-treated crumb rubber exhibited better mechanical and durability of concrete.

Keywords: *Concrete, Crumb rubber, Mixing, Peat water, Rice husk ash*

1. INTRODUCTION

Riau Province is one of the provinces in Indonesia. It is located on the island of Sumatra and is primarily covered with peatland, which spans around 3.8 million ha, nearly half of the province's total surface area [1]. Peat soil is known to cause severe problems in concrete construction due to its low bearing capacity and acidic water with a pH value range between 3-5. The low bearing capacity will cause the concrete slab on top of the soil to curl, which then generates excess tensile stress leading to the propagation of fine cracks on the concrete surfaces. Previous studies also showed that the high organic matter and acidic peat water could penetrate through the cracks and dilute the calcium content, thus reducing the strength of the concrete [2–5].

Several studies have been conducted to improve the ductility and durability of concrete, especially against acidic environments, including peatland. One of the ways to do this is by utilizing crumb rubber and pozzolanic materials. Crumb rubber is obtained by crushing and grinding a waste tire into uniform granular sizes varying from 0.075 to 4.75 mm and has been suggested as a replacement or additional material to improve the ductility and post-cracking behavior of concrete [6–13]. For example, [14] observed that crumb rubber acted as reinforcement and increased the concrete resistance against impact load to prevent immediate failure. Other researchers also reported similar results that adding crumb rubber enhanced the performance of concrete under the applied bending load and improved the energy

OPEN ACCESS

Affiliation
[1]Master Student of Department of Civil Engineering Universitas Gadjah Mada, Yogyakarta, Indonesia.
[2]Lecturer Departement of Civil Engineering, Riau University, Pekanbaru, 28293, Indonesia.
[3]Master Student of Departement of Civil Engineering, Riau University, Pekanbaru, 28293, Indonesia.
[4]Bachelor Student of Departement of Civil Engineering, Riau University, Pekanbaru, 28293, Indonesia.
[5]Quantity Surveyor & Document Control of Civil Team Lotte E&C for KINE Project.

***Correspondence**
Email: monita.olivia@lecturer.unri.ac.id

ORCID
Monita Olivia: 0000-0003-4516-7085

Received: March 26, 2025
Revised: June 27, 2025
Accepted: June 28, 2025

How to cite: Abdurrahman, H., Alfikri, N., Rijaldo, A., Qoryati, M, Marpaung, H. S. M., Wibisono, G., Olivia, M., (2025). Properties of concrete containing crumb rubber and rice husk ash mixing with peat water. *Journal of Applied Materials and Technology*, 6(2), 79–89. https://doi.org/10.31258/Jamt.6.2.79-89.

absorption capacity. However, it was noticeable that the compressive strength of the concrete decreased as the number of crumb rubber increased due to poor adhesion between crumb rubber and cementitious matrix [6,15–17]. Prior research on rubberized concrete indicated that the strength of concrete demonstrated an adverse relationship with rubber content [18–22]. Additionally, as the percentage and size of rubber particles increased, the decrease in performance became more apparent. Results for rubber concrete's compressive strength were lower with coarse rubber aggregates compared to fine ones [23,24].

There are a number of possible reasons for a decrease in the compressive strength of crumb rubber concrete. First, a significant discrepancy between the elastic modulus of rubber and the surrounding cement matrix quickens failure during the loading phase [25–28]. In addition, rubber's smooth surface hinders cement matrix adhesion, as numerous scholars have verified using SEM. [15,29,30]. Second, Poor binding strength between the mortar and rubber [27,31]. Lastly, cement matrix density decreased as a result of the size, density, and hardness of the crumb rubber. Several researchers have investigated and found that using pozzolanic ash filler is an effective approach to improve the low static mechanics of crumb rubber concrete. [32–35].

Pozzolanic materials such as fly ash, palm oil fuel ash, and rice husk ash which contain high silica content, have also been utilized to improve the concrete resistance against acid. The Calcium Silicate Hydrate (CSH), which formed through a pozzolanic reaction, refined the concrete pore structure and increased the concrete density. Many studies have been carried out to observe the effect of pozzolan in improving concrete resistance against acidic peat water. Study by [5] compared the properties of OPC, PCC, and POFA concrete after being immersed in peat water for 150 days. The acid resistance of concrete subjected to peat water was significantly increased by including pozzolanic materials from PCC and POFA. The compressive strength of concrete with rice husk ash (RHA) exposed to sulfate attack has also been studied by [36]. It was reported that concrete containing RHA had more resistant to sulfate attack than concrete without RHA. Therefore, adding mineral additives with pozzolan content is essential for improving the mechanical properties and microstructure of crumb rubber concrete as well as for reducing the amount of carbon emissions from cement utilization [37–39].

Another problem regarding concrete construction in the peat environment is the inadequate clean water in peatlands which causes the utilisation of peat water as an alternative to cast concrete on site to be unavoidable. Meanwhile, the hydration process to develop concrete strength essentially depends on the quality of water, both as mixing and curing water. Water for mixing concrete has to be clean and does not contain oil, alkali, organic substances, or other substances that can damage concrete [40]. Several studies have been conducted to understand how curing water quality affects concrete performance in recent years [41–43]. However, the investigation concerning the effects of mixing water quality on concrete is still minimal. Investigation on the change in the compressive strength of concrete when using water with a pH value of 3 and 7 as mixing and curing water has been done by [44]. The results showed that concrete mixed and cured with acidic water had a significant strength reduction compared to concrete mixed and cured with normal water. According to a study, mixing concrete with water at pH 3.2 reduced its strength by 30.58% when compared to tap water at pH 7.4 [45]. Another study by [4] reported that using acidic peat water on concrete generated a low compressive strength, high porosity, and high sorptivity compared to concrete with tap water.

Previous research on the optimum mixture of crumb rubber and rice husk ash on concrete as a proposed solution to improve concrete performance of concrete has been conducted [6]. In addition, with the same mixture, the compressive strength and porosity of crumb rubber rice husk ash (CR-RHA) concrete after being immersed in peat water for 28 days has also been investigated [46]. However, to simulate the on-site cast condition, this study aims to compare the effects of peat water and normal water as mixing and curing water on the properties of crumb rubber and rice husk ash concrete (CR-RHA).

2. MATERIALS AND METHODS

In this research, the crumb rubber and rice husk ash concrete (CR-RHA) samples were cast using Portland Cement Composite (PCC), crumb rubber (0.075-4.75 mm), rice husk ash (<0.075 mm), aggregates, water, and superplasticizer. Coarse and fine aggregates were brought from a local quarry with a specific gravity of 2.56 and 2.62. Crumb rubber was collected from the local tire industry and manually sieved to obtain a size of 0.075-4.75 mm. The specific gravity of crumb rubber was in range between 1.08-1.14 with fineness modulus of 2.62 as refer to previous research [47,48]. The number of crumb rubber and rice husk ash used on the concrete followed the optimum mixture from a previous study by [6], which was 5% crumb rubber and 10% rice husk ash by volume fine aggregate and volume cement, respectively. Plain PCC concrete was also cast as a control.

In contrast to the prior study, the crumb rubber was treated to compensate for the shortage of bonding between the crumb rubber and cement paste. Numerous studies reported rubber particles that have been treated using NaOH have a rougher surface, enhancing the physical interlock between the rubber and cement paste [17,23,49,50]. However, as we use RHA in our crumb rubber concrete, additional chemical reactions could be occurred between RHA and NaOH. Therefore, in this study, the crumb rubber was treated by soaking it in water for 24 hours to remove the entrapped air in the rubber particles and promote the bond between the rubber and the cement matrix. This method referred to a study by [51], which showed higher compressive strength than untreated crumb rubber.

Peat water used in this study for mixing water and curing water was taken from Rimbo Panjang, Riau Province. The physical and chemical characteristics of peat water compared to the required drinking water qualities provided by the [52] are shown in Table 1. According to the SNI 2847 standard, undrinkable water cannot be used in concrete mixtures since it must be free of harmful substances, such as organic compounds, acids, salts, and alkalis, which are regulated under the standards for drinkable water. It can be seen that peat water has a pH value of 5, indicating that it is more acidic than drinking water. Also, the high organic content in the peat water can obstruct the cement hydration process causing slower strength development on the concrete.

Table 1. Physical and chemical characteristics of peat water.

Parameters	Unit	Dringking water qualities [52]	Results
Color	TCU	< 15	34.6
Turbidity	NTU	< 5	15.9
Iron (Fe)	mg/L	< 0.3	0.8845
Alkalinity	mg/L	< 500	4.59
Chloride	mg/L	< 250	2.34
Manganese (Mn)	mg/L	< 0.4	0.2321
pH value	-	6.5 – 8.5	5
Sulphate	mg/L	< 250	68.2
Organic content	mg/L	< 10	28.38

Table 2. Mixture composition of PCC and CR-RHA concrete per m^3.

Type	Cement (kg)	Fine Agg (kg)	Coarse Agg (kg)	Water (kg)	CR (kg)	RHA (kg)	SP (kg)
PCC	599	505	1074	178	-	-	-
CR-RHA	599	505	1074	178	5.36	4.17	5.99

The CR-RHA concrete and PCC concrete samples were designed to meet a compressive strength of 35 MPa with a water-cement ratio of 0.3, and the mixture composition is shown in Table 2 below. In addition, a superplasticizer was added to CR-RHA concrete by 1% of the cement weight to increase the workability. Both types of concrete were cast into 105x210 mm cylindrical specimens for the compressive test, 150x300 mm cylindrical specimens for the splitting tensile test, and 105x105 mm cylindrical for the porosity test. Concrete mixed with normal water was cured in the normal water, and concrete mixed using peat water was treated in the peat water for 56 days. In this paper, PCC and CR-RHA concrete were given a code refer to the water used for mixing and curing. PCC N stands for PCC concrete mixed and cured with normal water, while PCC P represents PCC concrete mixed and cured with peat water. The exact meaning also applies to CR-RHA N and CR-RHA P. The compressive, splitting tensile, and porosity tests were conducted following SNI 03-1974-2011, SNI 03-2491-2014, and ASTM C642, respectively.

3. RESULT AND DISCUSSION

3.1. Effect of peat water on concrete surface. Figure 1 presents the difference in CR-RHA concrete after being immersed for 56 days. The concrete that was cured in normal water (CR-RHA N) benefited from a chemically neutral environment that allowed the cement particles to fully hydrate. The presence of clean water facilitated the essential reactions to occur efficiently, leading to the formation of calcium silicate hydrate (C-S-H) and calcium hydroxide which both required for the strength and integrity of the concrete matrix [44]. As a result, the CR-RHA N displayed a smooth, dense, and uniform surface with minimal imperfections, indicating proper setting as shown in Figure 1(a).

In contrast, CR-RHA P that cured in peat water introduces several unwanted effects on concrete surfaces due to peat chemical composition. Peat water has a high concentration of organic materials and is frequently acidic (low pH). By interacting with calcium hydroxide and preventing the production of C-S-H, these substances may disrupt the hydration process and potentially damage the concrete [3,4,53]. Additionally, the organic matter can become embedded in the concrete, causing noticeable discoloration and dark blotchy appearance as shown in Figure 1(b).

3.2. Compressive strength. Figure 2 shows the results of compressive strength tests conducted after the concrete had been cured for 3, 7, 28, and 56 days in normal and peat water. In general, either mixed and cured with normal or peat water, both types of concrete showed an increase in strength at all ages due to the cement hydration process and pozzolanic reaction. The compressive strength for both types of concrete when mixed and cured in normal water at 28 days was 35.03 MPa and 35.83 MPa, respectively, for PCC and CR-RHA concrete. These numbers showed that both concretes complied with the design strength. Furthermore, the highest compressive strength was obtained by CR-RHA N at 56 days with a value of 42.84 MPa.

Based on the studies about crumb rubber concrete in recent years, there was an adverse effect of incorporating crumb rubber toward the compressive strength development of concrete. The voids that rubber creates in concrete results in a comparatively lower compressive strength [25,26,29,54–56]. The main reason was due to poor adhesion between smooth-surface rubber particles and hardened cement paste, resulting formation of pores that lead to a weak interfacial transition zone (ITZ) in the concrete. Other reasons mentioned in previous studies were the significant difference in elastic modulus between rubber and aggregates, the non-uniform dispersion of crumb rubber in the concrete, and the hydrophobic habit of rubber that entraps air, thus accumulating the air volume in the concrete mixture [11,14,57]. However, it can

Figure 1. Concrete surface after immersion for 56 days. (a) CR-RHA P (b) CR-RHA N.

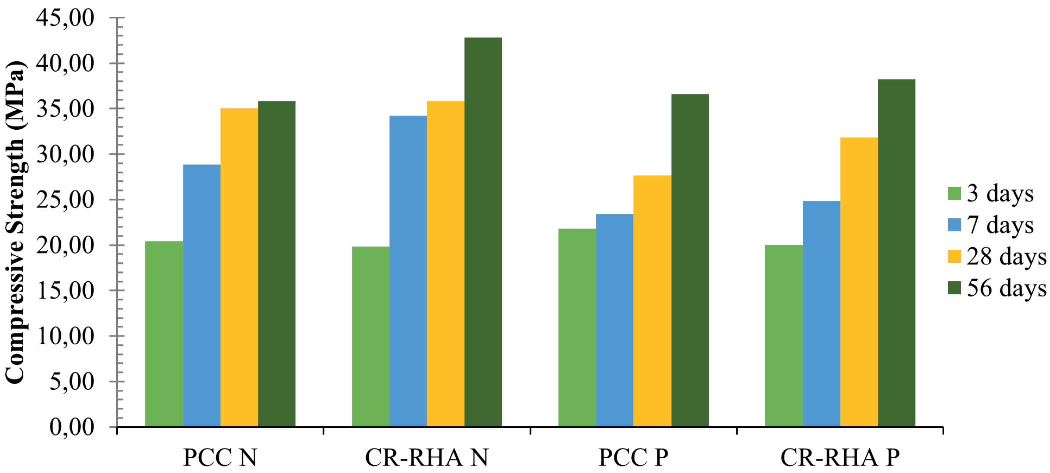

Figure 2. Compressive strength of PCC and CR-RHA concrete mixed and cured in normal and peat water for up to 56 days.

be seen from Figure 2 that CR-RHA showed higher compressive strength compared to PCC concrete both in normal water and peat water. Compressive strength enhancement on CR-RHA concrete due to crumb rubber being soaked in water for 24 hours before mixing resulted in a better bond between crumb rubber and hardened cement paste. The result was coherent with the study by [51], which also concluded that the applied method prevents early crack initiation due to the poor bond of crumb rubber and cement under a given load. By treating rubber crumbs with water, [58] demonstrated a similar result, minimizing the strength loss by around 16%.

The effect of peat water as mixing and curing water for both types of concrete was seen as peat water reduced concrete's early strength gain until 28 days. Acidic peat water and high organic content attacked the Calcium (Ca) content in cement which then delayed the hydration process resulting in lower strength at early ages [4,5,57]. A previous study by [59] found that concrete surfaces are eroded in acidic environments, leading to the formation of cracks and the degradation of surface layers. Nevertheless, it was found that the percentage loss of strength lowers as the number of crumb rubber replacing fine aggregates increases. It was due to the hydrophobic nature of crumb rubber which absorbs barely any water, making it highly resistant against the corrosive effects of acid from peat water [60]. Study by [61] presents similar findings, showing that rubberized concrete is less susceptible to acidic water curing than conventional concrete and is preferred for environments where the concrete and chemical agents come into constant contact.

After 56 days, the late pozzolanic reaction from PCC and rice husk ash improved the concrete by generating more calcium sili-

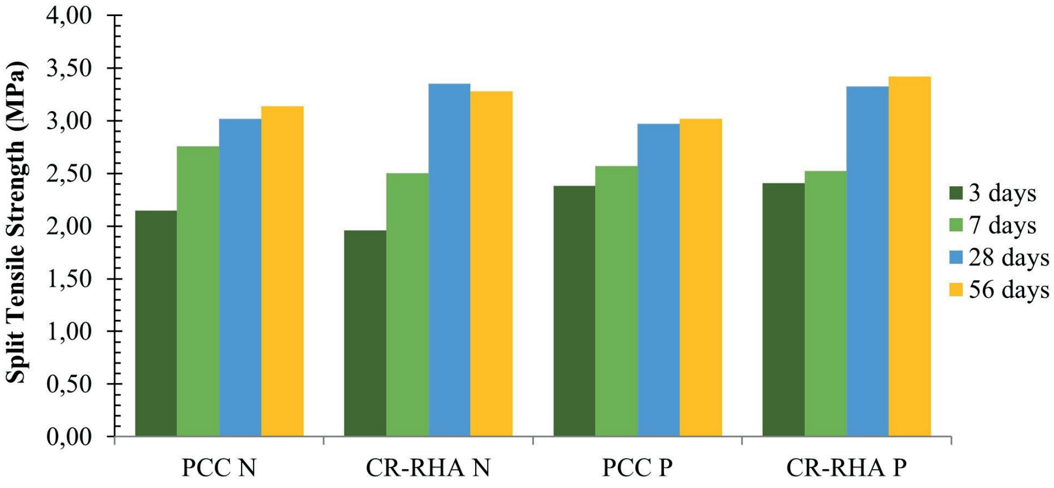

Figure 3. Splitting tensile strength of PCC and CR-RHA concrete mixed and cured in normal and peat water for up to 56 days.

cate hydrate (CSH), which filled the concrete pore, thus forming denser concrete. Overall, the loss in compressive strength of CR-RHA concrete is slightly lower compared to PCC concrete due to the additional pozzolan reaction from rice husk ash produced secondary CSH that refined the pore structure of concrete and improved the concrete resistance against acid attack from peat water [3, 62, 63].

3.3. Splitting tensile strength. The splitting tensile strength of PCC and CR-RHA concrete is shown in Figure 3. It can be seen that the tensile strength development for both types of concrete was similar to the results of compressive strength. This similar outcome was possible because both compressive and splitting tensile tests used the same approach to determine their values, which involved applying a distributed load to the concrete until it was split into two. Generally, the splitting tensile strength of CR-RHA concrete was relatively higher than PCC concrete in all variations of mixing water and curing water at all ages, with the highest tensile strength obtained by CR-RHA P at 3.42 MPa. The crumb rubber in CR-RHA concrete acted as a reinforcement which improved the performance of concrete in bearing a tensile load.

According to the previous studies that other researchers have conducted, the tensile load of crumb rubber concrete tended to decrease with increased crumb rubber content. The decrease was mostly reported due to the poor adhesion of crumb rubber to the cement matrix, which weakened the ITZ resulting in the cracks propagation when concrete received the load [64–67]. Furthermore, it is possible since crumb rubber is less stiff compared to fine aggregate, which affects the mass stiffness and load-bearing capability of the concrete [38,61,68,69].

However, based on Figure 3, it turned out that CR-RHA concrete had a greater tensile strength compared to PCC concrete. The possible reason was due to the treatment given to crumb rubber by submerging it in water for 24 hours which released the entrapped air on the rubber surface and improved the stickiness of crumb rubber with hardened cement [51]. Research has shown that, in contrast to untreated rubber, which has poor strength and a weak bond with the cement matrix, treated rubber exhibits better mechanical and durability characteristics [17,70–72]. According to [24], treated crumb rubber prevented concrete cracks and spalling from propagating. It was also noted that the inclusion of RHA increased the tensile strength of the concrete by delaying the development of cracks and controlling their extent and spread since the concrete microstructure was denser [38].

The change in the concrete tensile strength due to peat water is also shown in Figure 3. Compared to compressive strength, it can be observed that there was a relatively slight change for both types of concrete after being immersed in peat water for 56 days. Acidic water generally has a negative impact on the strength and durability of concrete. A study by [73] found that acidic water can delay concrete's setting times and reduce its flexural and tensile strengths by 22% and 41%, respectively. However, from Figure 3, the result showed that acidic peat water only had a minor effect on the tensile strength of PCC and CR-RHA concrete. The silica content from PCC cement and RHA induced more CHS gel through the pozzolanic reaction to improve the density and enhance the concrete resistance against acid. The results were similar to previous studies that pozzolan could help concrete develop its tensile strength even after being subjected to acid water for 150 days [62].

3.4. Porosity. The porosity test of PCC and CR-RHA concrete using different types of mixing and curing water was carried out at 3, 7, 28, and 56 days and the result is illustrated in Figure 4. In general, both types of concrete showed a declining trend throughout the curing age until 56 days due to the hydration process from cement and the pozzolanic reaction that fills the concrete pores, thus reducing the porosity. At 56 days, CR-RHA N showed the lowest porosity compared to other specimens at 8.23%, followed by PCC N at 9.48%.

Prior studies on the porosity of crumb rubber concrete revealed that the hydrophobic properties of rubber resist particles of water in the cement matrix, which causes air to trap and pores to form, weakening the bond at the interfacial transition zone (ITZ) [74,75]. However, according to Figure 4, CR-RHA concrete showed a lower porosity than PCC concrete in all variations of mixing and curing water due to the excess pozzolan from rice husk ash that fills the con-

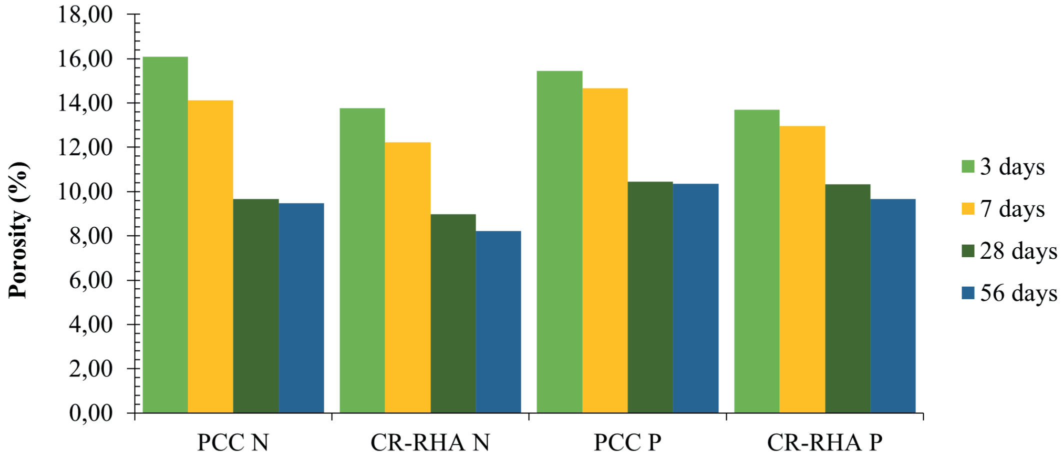

Figure 4. The porosity of PCC and CR-RHA concrete mixed and cured in normal and peat water for up to 56 days.

crete pore and significantly increases the density of the interfacial zone between the cement paste and the rubber [76,77].

The result also matched the abovementioned compressive strength, which showed that lower porosity tends to have a higher compressive strength. Moreover, the treatment given to the crumb rubber with a water-soaked method eliminated the air entrapped in the rubber surfaces, thereby preventing the formation of additional pores due to the inclusion of crumb rubber in the concrete mixture [46,51]. Compared to untreated rubber, pre-treated rubber has a denser microstructure in the ITZ, demonstrating stronger mortar bonding performance [17].

The effect of using peat water as mixing and curing water for both types of concrete can also be observed in Figure 4. At 3 and 7 days, the concrete had higher porosity than specimens mixed and cured with normal water. This result demonstrated that peat water has a negative impact on the porosity of concrete. Early exposure to acidic peat water diluted the calcium content from cement. Also, the organic matter delayed the generation of hydration products, thus increasing the number of pores in the concrete [3,62]. After 28 days, the pozzolanic reaction from PCC and RHA enhanced the pore structure in concrete by producing additional CSH gel, resulting in denser concrete. According to [8], additional SiO2 from pozzolan strengthened mortar-crumb rubber bonding, reduced porosity and the size of the ITZ, as well as improved both the mechanical and microstructure of crumb rubber concrete.

3.5. Comparative study. In this paper, the properties of CR-RHA concrete using peat water as mixing and curing water are compared with the previous study conducted by [6] and [46]. It is noteworthy that this paper used the same number of crumb rubber and rice husk ash in the concrete mixture obtained from the abovementioned studies. However, in this study, the crumb rubber is treated first by soaking it in water for 24 hours before pouring it into the mixture. The effect of the crumb rubber treatment is then observed and analyzed. The comparative study on compressive strength and tensile strength of CR-RHA concrete, compared to CR-RHA (2019), can be found in Figure 5 [6,46]. The CR-RHA specimens in this study were tested at 3, 7, 28, and 56 days while the CR-RHA (2019) samples were tested at 7, 14, and 28 days. It can be seen that at 28 days, the compressive strength of CR-RHA N was higher by 19.28% than CR-RHA (2019). The primary reason for this improvement was the treated crumb rubber that generated a better bond between the rubber surface and hardened cement paste than the previous mixes. This water-soaking method maintained the 28-day compressive strength of CR-RHA P to be almost the same as CR-RHA (2019), even after direct exposure to peat water. Although the treatment of crumb rubber showed insignificant change in the 28-day tensile strength of CR-RHA concrete as it is relatively similar to the previous study, the water-soaking method is recommended to improve the properties of CR-RHA concrete.

The porosity of CR-RHA N and CR-RHA P could not be compared directly with the previous study due to the application of different curing methods. Both CR-RHA N and CR-RHA P concrete were cured on each respective water immediately after removal from the mold, and the porosity tests were conducted at 3, 7, 28, and 56 days. Meanwhile, CR-RHA (2019) specimens were cured first in normal water for 28 days before being immersed in peat water. Therefore, the porosity tests were conducted at 0, 7, and 28 days after being cured in peat water or the same as 28, 35, and 56 days after the specimens were removed from the cast.

It can be seen from Figure 6 that CR-RHA (2019) concrete from the previous study [46] had higher porosity than CR-RHA N and CR-RHA P at 28 days, respectively, by 21.52% and 5.52%. This result was because the crumb rubber utilized in the CR-RHA (2019) concrete had not been treated with the water-soaking method for 24 hours. As a result, the untreated rubber would keep its hydrophobic nature that repels water and retains air on its surfaces. Due to this behavior, air bubbles became attached to rubber surfaces and consequently carried into the concrete mixture by the rubber particles, thus increasing the number of pores in the concrete. CR-RHA (2019) also showed a sudden increase in porosity after being subjected to peat water for 7 days or at a concrete age of 35 days due to the deterioration caused by acidic peat water. A similar event occurred to CR-RHA P, which concluded that using peat water as mixing and curing water delayed the formation of

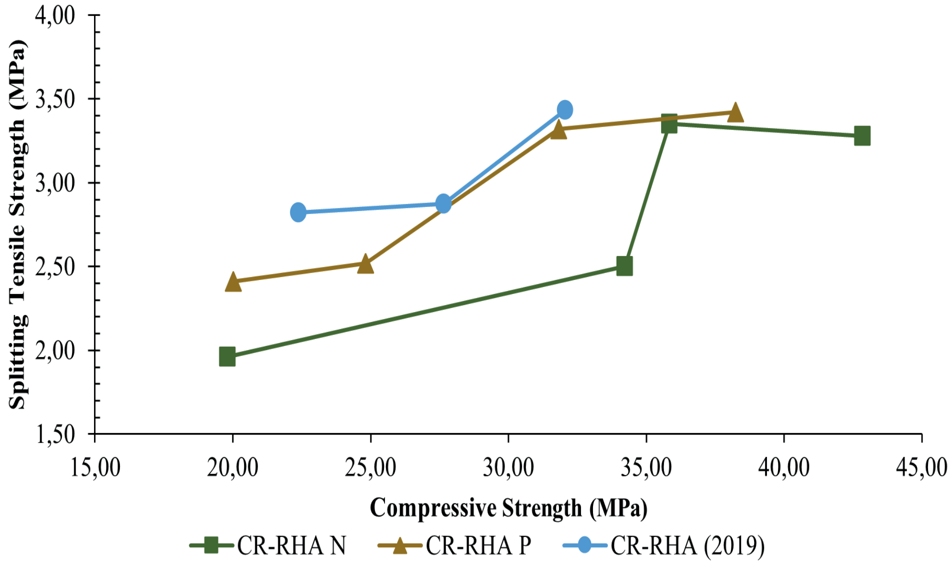

Figure 5. The comparative study on compressive strength and tensile strength of CR-RHA concrete.

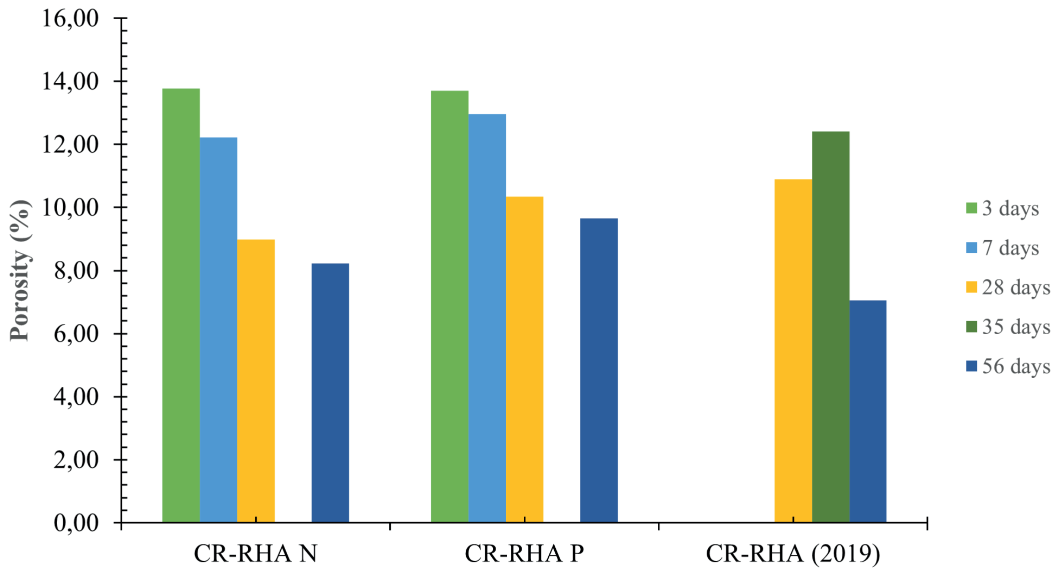

Figure 6. The comparative study on the porosity of CR-RHA concrete.

CSH that filled the concrete pore, thus generating higher porosity at early ages.

4. CONCLUSION

This study compares the effects of peat and normal water as mixing and curing water on the properties of crumb rubber and rice husk ash concrete (CR-RHA), i.e. compressive strength, tensile strength, and porosity. The number of crumb rubber and rice husk ash used on the concrete followed the optimum mixture from a previous study, which was 5% crumb rubber and 10% rice husk ash. However, an additional method was adopted to overcome the lack of adhesion between the crumb rubber and cement paste by submerging the crumb rubber in water for 24 hours before mixing. As a result, CR-RHA concrete and PCC concrete generally showed lower compressive strength, lower tensile strength, and higher porosity when mixed and cured with peat water compared to normal water. These results were mainly due to the high acidity of peat water that diluted the calcium content and delayed the formation of hydration products that could fill the concrete pore, generating higher porosity at early ages, which led to the strength reduction. However, due to the excess amount of pozzolan from rice husk ash, it was shown that CR-RHA concrete had better resistance as the loss in strength was relatively minor compared to PCC concrete. Moreover, compared to the previous study by [6] and [46], CR-RHA N and CR-RHA P had higher compressive strength and lower porosity due to the treatment that was given to the crumb rubber before being mixed to improve the bonding between crumb rubber and cement paste by submerging it to water for 24 hours. Although the treatment of crumb rubber showed insignificant change in the 28-day tensile strength of CR-RHA concrete as it is relatively similar to the previous study, the water-soaking method is recommended to improve the properties of CR-RHA concrete.

ACKNOWLEDGEMENTS

The study was a part of Penelitian Dasar Unggulan Perguruan Tinggi (PDUPT) scheme 2023 funded by Direktorat Riset dan Pengabdian kepada Masyarakat; Kementerian Pendidikan, Kebudayaan, Riset dan Teknologi (Kemendikbud Ristek) Republic of Indonesia Contract no. 052/E5/PG.02.00.PI/2023 and Penelitian Unggulan Perguruan Tinggi 2019 DIPA LPPM (Research Institute) Universitas Riau, Contract no. 980/UN.19.5.1.3/PT.01.03/2019. The authors thank Structural and Concrete Laboratory staff and the Final Year Project Students Batch 11 for their assistant and help during the lab work.

CREDIT AUTHOR STATEMENT

Abdurrahman, H: Writing, Data curation, and Formal analysis. **Alfikri, N**: Data curation and Formal analysis. **Rijaldo, A**: Data curation and Formal analysis. **Qoryati, M**: Data curation and Formal analysis. **Marpaung, H. S. M.**: Investigation and Validation. **Wibisono, G.**: Supervision, Conceptualization, and Methodology. **Olivia, M**: Supervision, Reviewing, Conceptualization, and Methodology.

DECLARATIONS

Conflict of interest The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

REFERENCES

[1] Central Bureau of Statistics, Riau Province in Numbers, BPS Provinsi Riau, Pekanbaru, 2019.

[2] O. Oueslati, J. Duchesne, Resistance of blended cement pastes subjected to organic acids: Quantification of anhydrous and hydrated phases, Cem Concr Compos 45 (2014) 89–101. https://doi.org/https://doi.org/10.1016/j.cemconcomp.2013.09.007.

[3] M. Olivia, T. Pradana, I.R. Sitompul, Properties of Plain and Blended Cement Concrete Immersed in Acidic Peat Water Canal, Procedia Eng 171 (2017) 557–563. https://doi.org/https://doi.org/10.1016/j.proeng.2017.01.372.

[4] M. Olivia, Ismeddiyanto, G. Wibisono, I.R. Sitompul, Early age compressive strength, porosity, and sorptivity of concrete using peat water to produce and cure concrete, AIP Conf Proc 1887 (2017) 020027. https://doi.org/10.1063/1.5003510.

[5] M. Olivia, I. Sitompul, E. Saputra, S. Sutikno, K. Yamamoto, Effectiveness of using pozzolanic material for concrete canal blocks in tropical peatland, IOP Conf Ser Mater Sci Eng 615 (2019) 012111. https://doi.org/10.1088/1757-899X/615/1/012111.

[6] H. Abdurrahman, G. Wibisono, M. Qoryati, I.R. Sitompul, M. Olivia, Mechanical properties of crumb rubber-rice husk ash concrete as a rigid pavement material, IOP Conf Ser Mater Sci Eng 615 (2019) 012112. https://doi.org/10.1088/1757-899X/615/1/012112.

[7] B.S. Mohammed, M. Adamu, Mechanical performance of roller compacted concrete pavement containing crumb rubber and nano silica, Constr Build Mater 159 (2018) 234-251. https://doi.org/https://doi.org/10.1016/j.conbuildmat.2017.10.098.

[8] M. Adamu, B.S. Mohammed, M. Shahir Liew, Mechanical properties and performance of high volume fly ash roller compacted concrete containing crumb rubber and nano silica, Constr Build Mater 171 (2018) 521–538. https://doi.org/https://doi.org/10.1016/j.conbuildmat.2018.03.138.

[9] H. Noorvand, G. Arce, M. Hassan, T. Rupnow, L.N. Mohammad, Investigation of the Mechanical Properties of Engineered Cementitious Composites with Low Fiber Content and with Crumb Rubber and High Fly Ash Content, Transp Res Rec 2673 (2019) 418–428. https://doi.org/10.1177/0361198119837510.

[10] M.N. Mohamad Ali Mastor, M.A. Ab Kadir, P.N. Shek, N. Zuhan, Hardened properties of concrete with different proportion of crumb rubber and fly ash, IOP Conf Ser Mater Sci Eng 849 (2020) 012038. https://doi.org/10.1088/1757-899X/849/1/012038.

[11] Fauzan, O.F. Nur, K. Albarqi, A.P. Melinda, Z. Al Jauhari, The Effect Of Waste Tyre Rubber On Mechanical Properties Of Normal Concrete And Fly Ash Concrete, International Journal of GEOMATE 20 (2021) 55–61. https://doi.org/10.21660/2020.77.5737.

[12] C.D. Isberto, K.L. Labra, J.M. Landicho, R. De Jesus, Effect of rice husk ash and crumb waste rubber tires to microstructure and strength of concrete, International Journal of GEOMATE 20 (2021) 16–21. https://doi.org/10.21660/2021.79.6196.

[13] N. Brari, Dr.H. Sood, Effect of Rice Husk Ash on Strength Properties of Crumb Rubber Concrete, in: 2017. https://api.semanticscholar.org/CorpusID:212476390.

[14] M.A. Aiello, F. Leuzzi, Waste tyre rubberized concrete: Properties at fresh and hardened state, Waste Management 30 (2010) 1696–1704. https://doi.org/https://doi.org/10.1016/j.wasman.2010.02.005.

[15] B.S. Thomas, R.C. Gupta, A comprehensive review on the applications of waste tire rubber in cement concrete, Renewable and Sustainable Energy Reviews 54 (2016) 1323–1333. https://doi.org/https://doi.org/10.1016/j.rser.2015.10.092.

[16] T. Gupta, S. Chaudhary, R. Sharma, Assessment of mechanical and durability properties of concrete containing waste rubber tire as fine aggregate, Constr Build Mater 73 (2014) 562–574. https://doi.org/10.1016/j.conbuildmat.2014.09.102.

[17] K. Najim, M. Hall, Workability and mechanical properties of crumb rubber concrete, Construction Materials 166 (2013) 7–17. https://doi.org/10.1680/coma.11.00036.

[18] M.M. Ul Islam, J. Li, R. Roychand, M. Saberian, F. Chen, A comprehensive review on the application of renewable waste tire rubbers and fibers in sustainable concrete, J Clean Prod 374 (2022) 133998. https://doi.org/10.1016/j.jclepro.2022.133998.

[19] R.J. Gravina, T. Xie, R. Roychand, Y. Zhuge, X. Ma, J.E. Mills, O. Youssf, Bond behaviour between crumb rubberized concrete and deformed steel bars, Structures 34 (2021) 2115–2133. https://doi.org/https://doi.org/10.1016/j.istruc.2021.08.076.

[20] O. Youssf, J.E. Mills, T. Benn, Y. Zhuge, X. Ma, R. Roychand, R. Gravina, Development of Crumb Rubber Concrete for Practical Application in the Residential Construction Sector – Design and Processing, Constr Build Mater 260 (2020) 119813. https://doi.org/https://doi.org/10.1016/j.conbuildmat.2020.119813.

[21] E.-S. Abd-Elaal, S. Araby, J.E. Mills, O. Youssf, R. Roychand, X. Ma, Y. Zhuge, R.J. Gravina, Novel approach to improve crumb rubber concrete strength using thermal treatment, Constr Build Mater 229 (2019) 116901. https://doi.org/https://doi.org/10.1016/j.conbuildmat.2019.116901.

[22] A. Farhad, Mechanical Properties of Waste Tire Rubber Concrete, Journal of Materials in Civil Engineering 28 (2016) 04015152. https://doi.org/10.1061/(ASCE)MT.1943-5533.0001429.

[23] R. Roychand, R.J. Gravina, Y. Zhuge, X. Ma, O. Youssf, J.E. Mills, A comprehensive review on the mechanical properties of waste tire rubber concrete, Constr Build Mater 237 (2020) 117651. https://doi.org/https://doi.org/10.1016/j.conbuildmat.2019.117651.

[24] S. Karunarathna, S. Linforth, A. Kashani, X. Liu, T. Ngo, Effect of recycled rubber aggregate size on fracture and other mechanical properties of structural concrete, J Clean Prod 314 (2021) 128230. https://doi.org/https://doi.org/10.1016/j.jclepro.2021.128230.

[25] N.N. Eldin, A.B. Senouci, Rubber-tire particles as concrete aggregate, Journal of Materials in Civil Engineering 5 (1993) 478–496. https://doi.org/10.1061/(ASCE)0899-1561(1993)5:4(478).

[26] Z.K. Khatib, F.M. Bayomy, Rubberized Portland cement concrete, Journal of Materials in Civil Engineering 11 (1999) 206–213. https://doi.org/10.1061/(ASCE)0899-1561(1999)11:3(206).

[27] H.S. Lee, H. Lee, J.S. Moon, H.W. Jung, Development of tire-added latex concrete, ACI Mater J 95 (1998) 356–364.

[28] E. Ganjian, M. Khorami, A.A. Maghsoudi, Scrap-tyre-rubber replacement for aggregate and filler in concrete, Constr Build Mater 23 (2009) 1828–1836. https://doi.org/https://doi.org/10.1016/j.conbuildmat.2008.09.020.

[29] A. Abdelmonem, M.S. El-Feky, E.-S.A.R. Nasr, M. Kohail, Performance of high strength concrete containing recycled rubber, Constr Build Mater 227 (2019) 116660. https://doi.org/https://doi.org/10.1016/j.conbuildmat.2019.08.041.

[30] A. Moustafa, M.A. ElGawady, Mechanical properties of high strength concrete with scrap tire rubber, Constr Build Mater 93 (2015) 249–256. https://doi.org/https://doi.org/10.1016/j.conbuildmat.2015.05.115.

[31] K.-H. Chung, Y.-K. Hong, Introductory Behavior of Rubber Concrete, J Appl Polym Sci 72 (1999) 35–40. https://doi.org/10.1002/(sici)1097-4628(19990404)72:1<35::aid-app3>3.0.co;2-b.

[32] Q. Ma, Z. Mao, J. Zhang, G. Du, Y. Li, Behavior evaluation of concrete made with waste rubber and waste glass after elevated temperatures, Journal of Building Engineering 78 (2023) 107639. https://doi.org/https://doi.org/10.1016/j.jobe.2023.107639.

[33] H.W. Iqbal, K. Hamcumpai, P. Nuaklong, P. Jongvivatsakul, S. Likitlersuang, C. Chintanapakdee, A.C. Wijeyewickrema, Effect of graphene nanoplatelets on engineering properties of fly ash-based geopolymer concrete containing crumb rubber and its optimization using response surface methodology, Journal of Building Engineering 75 (2023) 107024. https://doi.org/https://doi.org/10.1016/j.jobe.2023.107024.

[34] C.M. Copetti, P.M. Borges, J.Z. Squiavon, S.R. da Silva, J.J. de Oliveira Andrade, Evaluation of tire rubber surface pre-treatment and silica fume on physical-mechanical behavior and microstructural properties of concrete, J Clean Prod 256 (2020) 120670. https://doi.org/https://doi.org/10.1016/j.jclepro.2020.120670.

[35] K.A. Helal, A.M. Tahwia, O. Youssf, Performance of eco-friendly ECC made of pre-treated crumb rubber and waste quarry dust, Journal of Building Engineering 97 (2024) 110820. https://doi.org/https://doi.org/10.1016/j.jobe.2024.110820.

[36] G. Rodríguez de Sensale, Effect of rice-husk ash on durability of cementitious materials, Cem Concr Compos 32 (2010) 718–725. https://doi.org/https://doi.org/10.1016/j.cemconcomp.2010.07.008.

[37] A.M. Tahwia, M. Abd Ellatief, A.M. Heneigel, M. Abd Elrahman, Characteristics of eco-friendly ultra-high-performance geopolymer concrete incorporating waste materials, Ceram Int 48 (2022) 19662–19674. https://doi.org/10.1016/j.ceramint.2022.03.103.

[38] H.A. Mahmoud, T.A. Tawfik, M.M. Abd El-razik, A.S. Faried, Mechanical and acoustic absorption properties of lightweight fly ash/slag-based geopolymer concrete with various aggregates, Ceram Int 49 (2023) 21142–21154. https://doi.org/https://doi.org/10.1016/j.ceramint.2023.03.244.

[39] M.S. Tale Masoule, N. Bahrami, M. Karimzadeh, B. Mohasanati, P. Shoaei, F. Ameri, T. Ozbakkaloglu, Lightweight geopolymer concrete: A critical review on the feasibility, mixture design, durability properties, and microstructure, Ceram Int 48 (2022) 10347–10371. https://doi.org/https://doi.org/10.1016/j.ceramint.2022.01.298.

[40] T. Mulyono, Teknologi beton, Penerbit Andi, Yogyakarta (2004).

[41] H. Min, Z. Song, Investigation on the Sulfuric Acid Corrosion Mechanism for Concrete in Soaking Environment, Advances in Materials Science and Engineering 2018 (2018) 1–10. https://doi.org/10.1155/2018/3258123.

[42] R. Singh, S. Goel, Acid and Sulphate Resistance of Limestone Blended Pervious Concrete, Journal on Civil Engineering 9 (2019) 9–16.

[43] A.R. Erbektas, O. Isgor, W. Weiss, Comparison of Chemical and Biogenic Acid Attack on Concrete, ACI Mater J 117 (2020). https://doi.org/10.14359/51720293.

[44] I.T. Wicaksono, R. Nurwidayati, The Effect of pH Water on the Concrete Mixtures and Curing Condition on the Compressive Strength of Concrete, IOP Conf Ser Earth Environ Sci 999 (2022) 012006. https://doi.org/10.1088/1755-1315/999/1/012006.

[45] A. Agnihotri, P.V. Ramana, Fascinate in approaching pH Wa-

ter Consequences on Mechanical and Durability Properties, ASPS Conference Proceedings 1 (2022) 207–215. https://doi.org/10.38208/acp.v1.499.
[46] M. Qoryati, M. Olivia, G. Wibisono, Kuat tekan dan porositas beton campuran crumb rubber dan abu sekam untuk material perkerasan kaku di tanah gambut, Jom FTEKNIK 6 (2019).
[47] P. Gill, P. Jangra, R. Roychand, M. Saberian, J. Li, Effects of various additives on the crumb rubber integrated geopolymer concrete, Cleaner Materials 8 (2023). https://doi.org/10.1016/j.clema.2023.100181.
[48] M. Alizadeh, M.R. Eftekhar, P. Asadi, D. Mostofinejad, Enhancing the mechanical properties of crumb rubber concrete through polypropylene mixing via a pre-mixing technique, Case Studies in Construction Materials 21 (2024). https://doi.org/10.1016/j.cscm.2024.e03569.
[49] X. Colom, F. Carrillo, J. Cañavate, Composites reinforced with reused tyres: Surface oxidant treatment to improve the interfacial compatibility, Compos Part A Appl Sci Manuf 38 (2007) 44–50. https://doi.org/10.1016/j.compositesa.2006.01.022.
[50] G. Wypych, Handbook of adhesion promoters, Elsevier, 2023.
[51] I. Mohammadi, H. Khabbaz, K. Vessalas, In-depth assessment of Crumb Rubber Concrete (CRC) prepared by water-soaking treatment method for rigid pavements, Constr Build Mater 71 (2014) 456–471. https://doi.org/10.1016/j.conbuildmat.2014.08.085.
[52] Ministry of Health, Drinking Water Quality Requirements, Jakarta, Indonesia, 2010.
[53] R. Sianturi, M. Olivia, E. Saputra, Kuat Tekan dan Sifat Fisik Beton OPC, OPC POFA, dan PCC Menggunakan Air Gambut sebagai Air Pencampur Beton, Jurnal Online Mahasiswa Fakultas Teknik Universitas Riau 4 (2017) 1–8.
[54] M.M. Reda Taha, A.S. El-Dieb, M.A. Abd El-Wahab, M.E. Abdel-Hameed, Mechanical, fracture, and microstructural investigations of rubber concrete, Journal of Materials in Civil Engineering 20 (2008) 640–649. https://doi.org/10.1061/(ASCE)0899-1561(2008)20:10(640).
[55] M. Gesoglu, E. Güneyisi, O. Hansu, S. İpek, D.S. Asaad, Influence of waste rubber utilization on the fracture and steel–concrete bond strength properties of concrete, Constr Build Mater 101 (2015) 1113–1121. https://doi.org/https://doi.org/10.1016/j.conbuildmat.2015.10.030.
[56] S. Raffoul, R. Garcia, K. Pilakoutas, M. Guadagnini, N.F. Medina, Optimisation of rubberised concrete with high rubber content: An experimental investigation, Constr Build Mater 124 (2016) 391–404. https://doi.org/https://doi.org/10.1016/j.conbuildmat.2016.07.054.
[57] V. Živica, Acidic resistance of materials based on the novel use of silica fume in concrete, Constr Build Mater 13 (1999) 263–269. https://doi.org/10.1016/S0950-0618(99)00029-X.
[58] H. Rostami, J. Lepore, T. e a1 Silverstraim, I. Zundi, Use of recycled rubber tires in concrete, in: Proceedings of the International Conference on Concrete, London, United Kingdom: Thomas Telford Services Ltd, 2000: pp. 391–399.
[59] K. Bisht, P. V. Ramana, Waste to resource conversion of crumb rubber for production of sulphuric acid resistant concrete, Constr Build Mater 194 (2019) 276–286. https://doi.org/10.1016/j.conbuildmat.2018.11.040.
[60] L. He, Y. Ma, Q. Liu, Y. Mu, Surface modification of crumb rubber and its influence on the mechanical properties of rubber-cement concrete, Constr Build Mater 120 (2016) 403–407. https://doi.org/10.1016/j.conbuildmat.2016.05.025.
[61] S. Tiwari, P. Gangwar, Evaluate the effect of acid attack on rubberised concrete using crumb tyre rubber and replacement of cement by alccofine, in: Mater Today Proc, Elsevier Ltd, 2021: pp. 3778–3782. https://doi.org/10.1016/j.matpr.2021.03.006.
[62] M. Olivia, U.A. Hutapea, I.R. Sitompul, L. Darmayanti, A. Kamaldi, Z. Djauhari, Resistance of plain and blended cements exposed to sulfuric acid solution and acidic peat water: a preliminary study, in: Proceedings of The 6th International Conference of Asian Concrete Federation, Seoul, Korea, 2014.
[63] M.A.M. Hassanean, S.A.M. Hussein, M. Elsayed, Shear behavior of reinforced concrete beams comprising a combination of crumb rubber and rice husk ash, Eng Struct 319 (2024). https://doi.org/10.1016/j.engstruct.2024.118862.
[64] H. Abdurrahman, G. Wibisono, I.R. Sitompul, M. Olivia, The Correlation Between Split Tensile and Flexural Strength with Compressive Strength of Crumb Rubber-Rice Husk Ash Concrete, in: S. Belayutham, C.K.I. Che Ibrahim, A. Alisibramulisi, H. Mansor, M. Billah (Eds.), Proceedings of the 5th International Conference on Sustainable Civil Engineering Structures and Construction Materials, Springer Nature Singapore, Singapore, 2022: pp. 581–592.
[65] S. Sgobba, M. Borsa, M. Molfetta, G.C. Marano, Mechanical performance and medium-term degradation of rubberised concrete, Constr Build Mater 98 (2015) 820–831. https://doi.org/10.1016/j.conbuildmat.2015.07.095.
[66] A.S.M. Mendis, S. Al-Deen, M. Ashraf, Behaviour of similar strength crumbed rubber concrete (CRC) mixes with different mix proportions, Constr Build Mater 137 (2017) 354–366. https://doi.org/10.1016/j.conbuildmat.2017.01.125.
[67] N.N. Gerges, C.A. Issa, S.A. Fawaz, Rubber concrete: Mechanical and dynamical properties, Case Studies in Construction Materials 9 (2018) e00184. https://doi.org/10.1016/j.cscm.2018.e00184.
[68] M. Elsayed, B.A. Tayeh, D. Kamal, Effect of crumb rubber on the punching shear behaviour of reinforced concrete slabs with openings, Constr Build Mater 311 (2021) 125345. https://doi.org/10.1016/j.conbuildmat.2021.125345.
[69] M.K. Ismail, A.A.A. Hassan, Shear behaviour of large-scale rubberized concrete beams reinforced with steel fibres, Constr Build Mater 140 (2017) 43–57. https://doi.org/10.1016/j.conbuildmat.2017.02.109.
[70] O. Youssf, J.E. Mills, R. Hassanli, Assessment of the mechanical performance of crumb rubber concrete, Constr Build Mater 125 (2016) 175–183. https://doi.org/10.1016/j.conbuildmat.2016.08.040.
[71] D. Li, Y. Zhuge, R. Gravina, J.E. Mills, Compressive stress strain behavior of crumb rubber concrete (CRC) and application in reinforced CRC slab, Constr Build Mater 166 (2018) 745–759. https://doi.org/10.1016/j.conbuildmat.2018.01.142.
[72] S.U. Azunna, F.N.A.A. Aziz, R.S.M. Rashid, N.B.A. Bakar,

Review on the characteristic properties of crumb rubber concrete, Cleaner Materials 12 (2024). https://doi.org/10.1016/j.clema.2024.100237.

[73] K.J. Taku, D.Y. Amartey, T. Kassar, Effect of Acidic Curing Environment on the Strength and Durability of Concrete, Civil and Environmental Research 7 (2015) 8–13. https://api.semanticscholar.org/CorpusID:54890054.

[74] N.F. Medina, R. Garcia, I. Hajirasouliha, K. Pilakoutas, M. Guadagnini, S. Raffoul, Composites with recycled rubber aggregates: Properties and opportunities in construction, Constr Build Mater 188 (2018) 884–897. https://doi.org/10.1016/j.conbuildmat.2018.08.069.

[75] L.H. Chou, C.-K. Lu, J.-R. Chang, M.T. Lee, Use of waste rubber as concrete additive, Waste Management & Research 25 (2007) 68–76.

[76] R. Roychand, S. De Silva, D. Law, S. Setunge, Micro and Nano Engineered High Volume Ultrafine Fly Ash Cement Composite with and without Additives, Int J Concr Struct Mater 10 (2016) 113–124. https://doi.org/10.1007/s40069-015-0122-7.

[77] M. Mazloom, A.A. Ramezanianpour, J.J. Brooks, Effect of silica fume on mechanical properties of high-strength concrete, Cem Concr Compos 26 (2004) 347–357. https://doi.org/10.1016/S0958-9465(03)00017-9.