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Physical Strength of Mortar with Treated Crumb Rubber as Partial Replacement for Fine Aggregate

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Abstract: Mortar offers an excellent opportunity to replace ingredients like fine aggregate with tyre rubber waste in the form of crumbs. It offers excellent environmental and technical benefits in terms of sustainable concrete production. The lack of bonding between crumb rubber and cement paste can be overcome by treating crumb rubber with sodium hydroxide. This study aims to identify the use of crumb rubber in mortar, determine the optimal percentages of crumb rubber in mortar, and investigate the mechanical and physical properties of treated crumb rubber. This paper uses a mixed proportion of 1:4 and a water-cement ratio of 0.50. Five different fine aggregate replacement percentages (0.00, 3.00, 6.00, 9.00, and 12.00 %) were investigated. The mortar compressive strength, density, and water absorption were evaluated after seven days and 14 days. The compressive value for mortar with 3.00 % crumb rubber shows the highest value 21.63 MPa after 14 days compared to the other replacement ratio. Density for mortar cube shows a decrement when the percentage of treated crumb rubber increases. For the mortar water absorption, the highest percentage is at 12.00 % crumb rubber replacement which is 11.76 %, and it found that the water absorption is increased with increasing crumb rubber percentage.

Keywords: Mortar, Sodium hydroxide, Crumb Rubber, Compressive Strength, Water Absorption

1. Introduction

Due to an ever-growing population, many new building structures are needed in rising countries. It's hard to keep up with the rising costs of building supplies. Traditional construction materials such as cement, sand, and stones are crucial to producing mortar and concrete. Because of their rising costs,

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researchers are exploring the possibility of utilising industrial, construction, and agricultural waste as a building material.

The main components are fine aggregates, Portland cement (limestone), and water to make a mortar. The mortar's quality and strength might vary significantly regarding the mixing proportion. Mortar has been used in various applications and it is considered very affordable, especially in the construction industry.

Rubber can be used as a binder or replace fine and coarse aggregates in concrete and mortar. Carbon dioxide emissions can be reduced while overall environmental sustainability is improved by using crumb rubber in any engineering cementitious composite [1] [2].

Weak adhesion between rubber and cement can lead to a considerable decrease in the strength of mortar that incorporates recycled tyre crumbs. The lower specific gravity of tyre crumbs also results in the reduction of the unit weight of mortar. However, reduced compressive strength has hindered the uptake of recycled tyre crumbs in concrete or mortar. Loss of strength has primarily been attributed to poor adhesion between recycled tyre crumb and cement mortar due to recycled tire crumb's hydrophobic (water-repelling) nature.

Treatment of tyre crumbs with sodium hydroxide (NaOH) solution has been used to increase adhesion between cement and rubber by etching the surface of the crumbs resulting in increased strength [3] [4] [5].

1.1 Problem Statement

There has been a dramatic increase in the amount of rubbish generated nowadays. Today, an estimated 8 billion tyres are thrown out around the world. That doesn't even consider that this scenario has deteriorated to the point where it's reflected in many other nations across the world. According to the Malaysian Ministry of Housing and Local Government's National Solid Waste Management Department's yearly report, around 0.3 million tonnes of scrap tyres are created [6]. It was predicted that this number would rise at a rate of 5% per year, in line with the rise in automobile usage. The amount of scrap tyres that would be created by 2025 is likewise projected to be around 0.4 million tonnes [7]. Because of this, effective recycling and waste management procedures are critical to preventing any significant contamination from taking place. If the vast volume of rubber tyres is not properly recycled and disposed, the environment would be severely harmed. Therefore, it is possible to implement solutions such as the reuse of used tyres from the second-hand market, the retreading of tyres, and the recovery of material from chopped, shredded, and completely micronized tyres. Recycling crumb rubber particles in concrete or mortar is a viable option to reduce waste. Recycling used tyres in construction is also an environmentally friendly way to reduce waste and save money [9]. Crumb rubber particles have been extensively studied as a filler ingredient in conventional concrete [10].

2. Equipment and Methods

There was an appropriate methodology process to achieve this study's objectives. Several procedures to conduct the study have been selected to achieve this study, as shown in the overview of the methodology process in Figure 1.

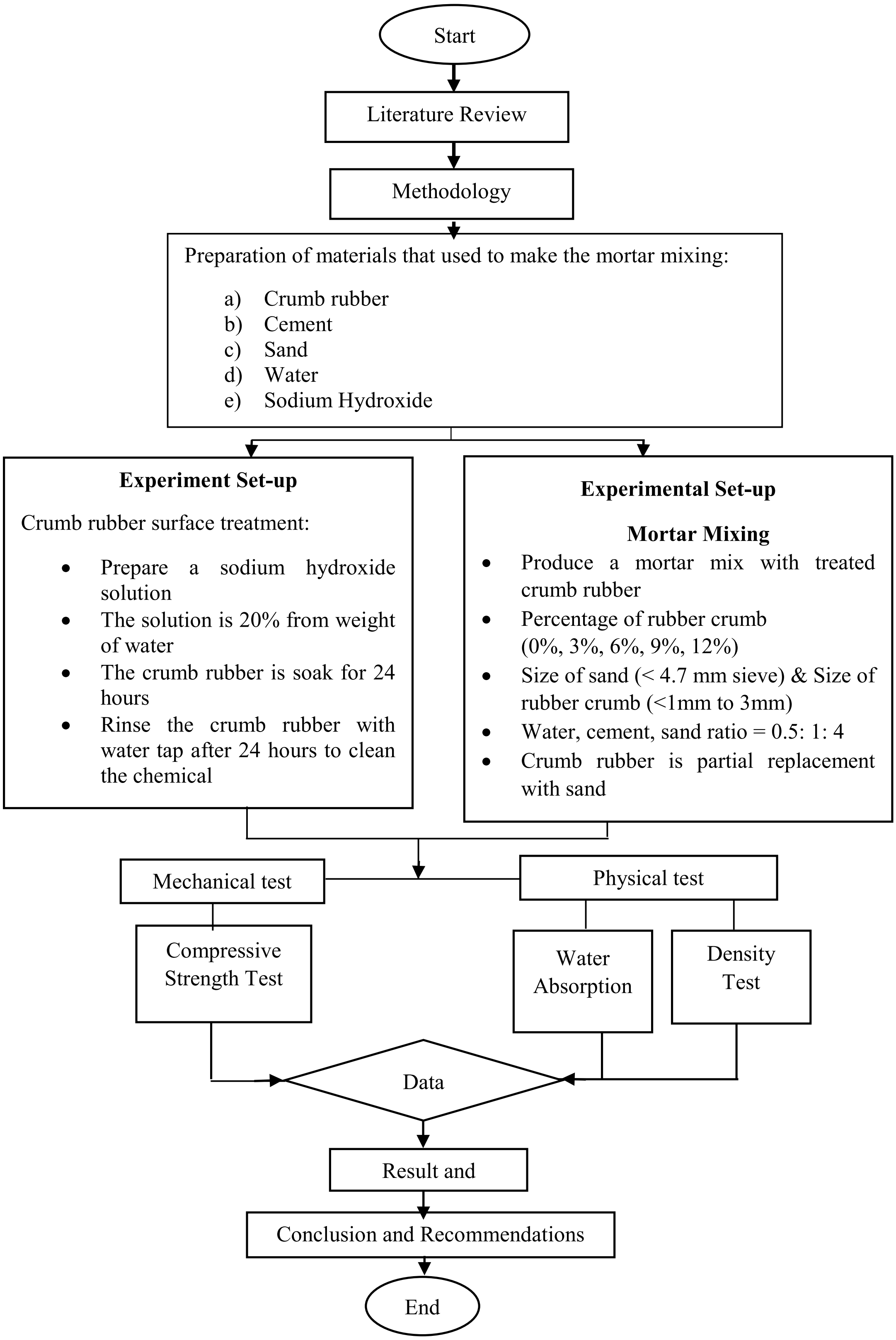

Figure 1: Methodology Chart

2.1 Material of crumb rubber mortar

2.1.1 Cement

The cement used in this research to make the mortar mixture is Type I ordinary Portland cement (OPC). The cement was taken from the UTHM laboratory. Table 1 shows the physical properties and chemical properties of the cement. The OPC was allowed to pass through a 300 mm opening sieve based on ASTM C150 to separate the cement clinker before being kept in an airtight container to avoid contact with moisture in the air, as hydrated cement particles will interfere with the formation of the calcium silicate hydrate gel.

Table 1: Chemical and physical properties of Orang Kuat cement manufacture by YTL

Test		Unit	Specification MS EN 197-1: 2014 CEM I 42.5N	Test result
			Chemical Composition	
Insoluble Residue		%	≤ 5.0	0.4
Loss On Ignition (LOI)		%	≤ 5.0	3.2
Sulphate Content (SO_3)		%	≤ 3.5	2.7
Chloride ($CI^{o)}$)		%	≤ 1.0	0.02
			Physical Properties	
Setting Time (Initial)		mins	≥60	130
Soundness		Mins	≤ 10	1.0
Compressive Strength (Mortar Prism)	$\frac{2\ days}{28\ days}$	$\frac{MPa}{MPa}$	$\frac{\geq 10}{\geq 42.4;\ \leq 62.5}$	$\frac{29.7}{48.9}$

2.1.2 Fine aggregate

A mixture of mining and river sand was used as aggregate. Fine sand was used to increase the tensile strength. The particle size distribution of fine aggregate was determined using sieve analysis. The sieves used have size graduations of 0.075 mm until 4.75 mm respectively. The coarsest sieve was placed at the top and the finest sieve was placed at the bottom of the sieve analysis.

2.1.3 water

Water is one of the primary raw materials needed to produce the mortar. Because it will affect the hydration process of the specimens, the water must be clean and free of impurities. The water used to mix the mortar was compliant with ASTM C1602. Raw water can be derived from various sources, including mixed water, non-potable water, mixing water, and potable water, as long as the water does not include any harmful contaminants that could short- or long-term influence the cement's hydration process. Tap water was used in this experiment as the mixing water for the mortar block casting and 0.50 % water-cement ratio was applied.

2.1.4 Crumb rubber

The crumb rubber was taken from a rubber factory at Muar, Johor. The maximum size of the crumb rubber was 3.00 mm. Figure. 2 shows the particle of crumb rubber used in this research. Compared to sand, crumb rubber contains irregular circular forms while sand has irregular shapes. The crumb rubber was used as a partial replacement for fine aggregate. Crumb rubber particles were sieved between 0.075 mm and 4.74 mm (No.4 and No.200 sieve) sieves. 0.00 %, 3.00 %, 6.00 %, 9.00 %, and 12.00 % are the percentages of replacement that are used.

Figure 2: Crumb rubber particle is taken from rubber factory in Muar

2.1.5 Sodium Hydroxide

NaOH was used as a surface treatment for crumb rubber before being mixed with other raw mortar materials. The crumb rubber was soaked with 20.00 % NaOH solution for 24 hours in a container and then rinsed with tap water to prevent any side effects to mortar. The pH of water is checked to make sure it becomes 7. The total time of washing that needs to remove the NaOH solution from the rubber surface is around 30-45 minutes. After that, the crumb rubber was allowed to dry before it was used to mix.

2.1.6 Mortar mould

To test compressive strength and water absorption, a mould with dimensions of 100 mm x 100 mm x 100 mm was used to cast the mortar specimens. Before utilising the moulds, they were cleaned and checked to ensure no substantial leftovers from prior work. After that, the inner surface of the molds was grease and coated for ease of demolding after the mortar had hardened.

2.2 Mix design

The cement mortar for this research was mixed manually. To begin, all of the raw materials, including cement, sand, and treated crumb rubber, were dry mixed. Then, water was added to the mixture and thoroughly mixed again. 4 sets of mixed proportions of treated crumb rubber mortar and one controlled mix were produced. The controlled mix did not contain crumb rubber particles was set as the reference for the other mix proportions. Next, four sets of mortar were mixed with a different ratio of crumb rubber as fine aggregate replacement. The proportion of crumb rubber particles ranges from 3.00 % to 12.00 %, with an interval of 3.00 % respectively, as shown in Table 2. The cement mortar mixture had a weight-to-weight ratio of 1:4:0.5 for cement, sand, and water. The fine aggregate was partially replaced by 0.00 %, 3.00 %, 6.00 %, 9.00 %, and 12.00 % of crumb rubber in the mixing and there is one control sample without any replacement of fine aggregate.

Table 2: Mix design for treated crumb rubber mortar

Designation	Replacement of Rubber Particles (%)	Water/Cement Ratio
0%	0	0.5
3%	3	0.5
6%	6	0.5
9%	9	0.5
12%	12	0.5

Table 3: Weight of material for crumb rubber mortar mix

Mortar mixture	Cement (KG)	Sand (KG)	Water (L)	Crumb rubber (KG)
0.00 %	2.5	10	1.25	0
3.00 %	2.5	9.7	1.25	0.3
6.00 %	2.5	9.4	1.25	0.6
9.00 %	2.5	9.1	1.25	0.9
12.00 %	2.5	8.8	1.25	1.2

The weight of material for crumb rubber mortar mix in this study is shown in Table 2. To determine the average compressive strength of each combination, three cement mortar specimens were cast and tested. Each specimen was cast and compacted in three layers. All specimens were left for 24 hours after casting before being demolded and cured in a curing tank at 25 °C for 7 and 14 days.

2.3 Crumb rubber surface treatment

When treated rubber is mixed into cement mortar, the cement hydration surrounding the rubber particles can be improved due to the weak alkali state created by the NaOH solution. Furthermore, the NaOH solution treatment increases the hydrophilicity of rubber aggregate, lowering the porosity between rubber particles and cement paste. As a result, rubber and cement paste adhesion might be improved. 20.00 % NaOH by water weight was used to make the pretreatment solution. Rubber tyre aggregates were soaked in the solution for 24 hours before being mixed into the mortar. The rubber particles were washed with tap water numerous times after being treated with the NaOH solution until the pH of the washing water was near to neutral. Finally, the treated rubber particles were allowed to dry at room temperature. Figure 3 shows how to treat crumb rubber with sodium hydroxide solution.

Figure 3: Process of crumb rubber treatment with sodium hydroxide solution

2.4 Mortar mixing, casting, and curing procedure

The mortar mixing and curing test specimen procedure were under control, with standard practice in the laboratory. Before mixing all the material, the crumb rubber was treated using sodium hydroxide for 24 hours, and then it was dry before being used. In this experiment, hand mixing is used to mix all materials according to the mix design. All dry ingredients, such as fine aggregate, crumb rubber, and cement, were mixed first, and then water was added. The mixtures are mixed until the mortar mixtures are uniformly mixed and well prepared, and the homogeneity of the mortar mix is visually assessed. Before pouring the fresh mortar mixture, the inner mould surface was well lubricated with a layer of oil. The fresh mortar mixture was poured into the mould in three layers. Rod tamping was used to compact the mortar cube specimens. To give a smooth surface flush, the outermost layer of mortar was finished with a trowel to level off the slightly overfilled concrete at the top of the mould. After casting, the mortar cube was allowed to sit for 24 hours before being demolded. Each mortar block must be fully submerged in water to ensure an equitable curing process and allow them to hydrate for 7 and 14 days, respectively. The water curing tank was made of non-corroding material and kept the water temperature at 25-28 °C at all times.

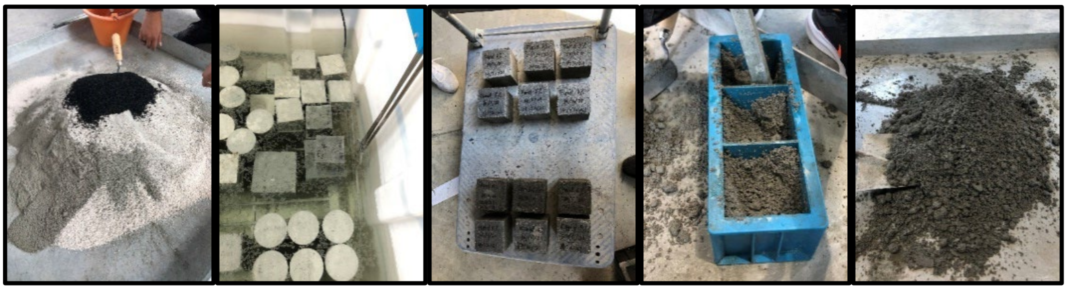

Figure 4: Mixing process of crumb rubber mortar

2.5 Test Procedures

The compressive strength of the cement mortar specimens was tested according to ASTM C109. The compressive strength of specimens was measured using the AUTOMAX Pro compressive testing machine shown in Figure 6. The loading rate was 0.70 MPa/s. Throughout the testing procedure, the loading rate remains constant.

Figure 5: Mortar cube specimen

Figure 6: AUTOMAX Pro compressive testing machine

3. Results and Discussion

3.1 Compressive Strength Test

Figure 7 depicts the growth of compressive strength with a curing duration of 7 and 14 days for hardened cement mortar containing 0.00 %, 3.00 %, 6.00 %, 9.00 %, and 12.00 % treated crumb rubber for fine aggregate replacement. The different values of compressive strength on days 7 and 14 where observation from the graph and 0.00 % sample have a higher value than another sample. The conclusion from this testing is based on a graph, mortar with no crumb rubber gives the highest compressive strength, and the mortar with crumb rubber shows a decrement in every percentage replacement. This is because the absence of adequate bonding between cement paste and crumb rubber particles, as opposed to fine aggregate and cement paste, explains this drop in performance. Furthermore, the graph shows that the lowest compressive strength value is 12.00 % crumb rubber replacement because the samples have too much void. The increment of crumb rubber in the mortar affected the strength of the mortar itself. Senin et al. [11] found that the rise in compressive stress for 3.00 % to 5.00 % was caused by the fine size of rubber ash used as gap fillers. However, using more than 5.00 % rubber ash reduces compressive strength due to the high rubber ash concentration in cement mortar samples. Because rubber is an elastomer, including crumb rubber into cement concrete reduces the compressive strength of the concrete significantly. The use of a small amount of crumb rubber content should be managed to maintain adequate compressive strength [12].

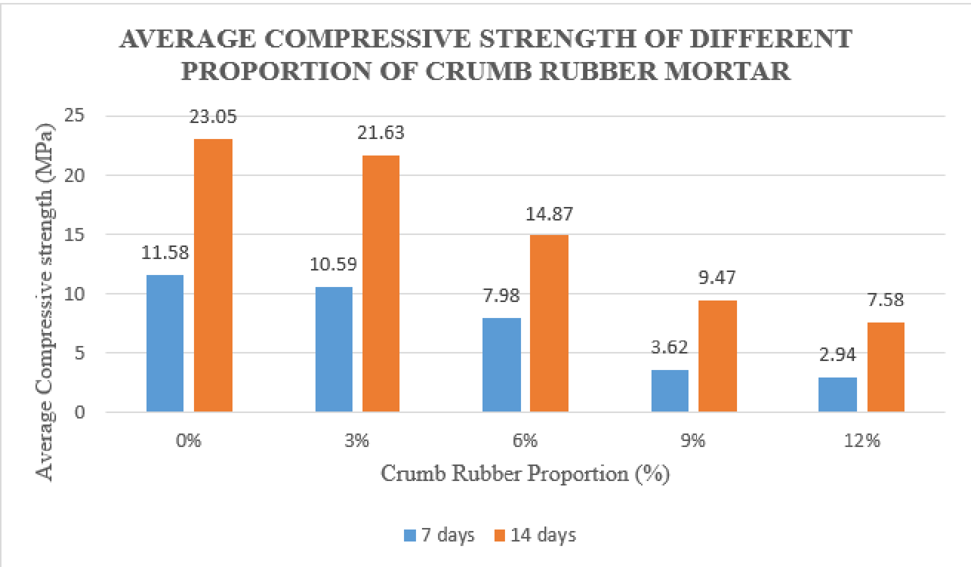

Figure 7: Average compressive strength of different proportions of crumb rubber mortar

3.2 Density of mortar

The addition of treated crumb rubber decreased the density of the cement mortar specimens. Figure 8 depicts the density of the mortar specimens at 7 and 14 days for 0.00 %, 3.00 %, 6.00 %, 9.00 %, and 12.00 % crumb rubber. At 14 days, the density of the 0% specimen was the greatest compared to the others, while the density of the 12.00 % specimen was the lowest compared to the others. The density of the cement mortar samples has reduced over time.

The average density of crumb rubber mortar at seven days is 2000 Kg/m^3, 1950 Kg/m^3, 1900 Kg/m^3, 1850 $Kg/m^{3,}$ and the lowest is 1800 Kg/m^3. The density of the sample constantly decreased at age 14 days to 1950 Kg/m^3, 1900 Kg/m^3, 1850 Kg/m^3, 1750 $Kg/m^{3,}$ and 1700 Kg/m^3. The sample with a high percentage of treated crumb rubber has low density than the control sample with a high-density value. The result can conclude that the mass affected the density of the crumb rubber mortar sample. This is because the 12.00 % replacement ratio has a high percentage of crumb rubber, and the sample becomes lightweight. The lighter the sample, the density value becomes low. Besides that, the density also decreases days by day, which is the value of average density sample 12.00 % ratio is 1800 Kg/m^3 at days 7, the density value increases to 1700 Kg/m^3. In addition, different weights for each sample can also cause temporary density values, which may be due to the concrete's current compaction to the mould. The findings are backed by a recent study by Senin et al. [11], which discovered the 3 per cent rubber replacement had the lowest density because the voids in the cement mortar specimen were not filled by the rubber ash and replacing rubber ash with more than 5.00 % affects density owing to high rubber ash concentration in cement mortar specimens.

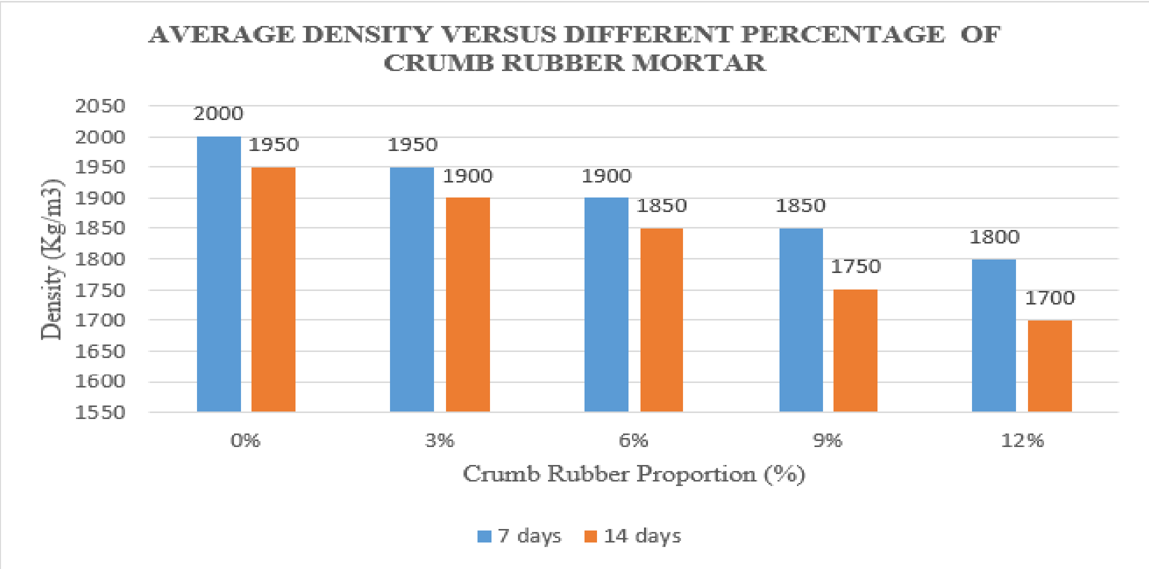

Figure 8: Average density versus different percentages of crumb rubber mortar

3.3 Water absorption test

Figure 9 shows the average value in percentage (%) of water absorption for each sample of crumb rubber mortar. From the result, the higher value of water absorption rate is a sample with 12.00 % crumb rubber replacement. The average value of the control sample at day 7 is 9.58 %, slightly increased to 10.31 % on day 14. For a 3.00 % replacement sample, the average water absorption is 8.86% for seven days and 9.68 % for 14 days. The mortar sample with 6.00 % crumb rubber replacement shows that the average water absorption value is constant at 10.01 % for both seven days and 14 days. Lastly, for the 12.00 % crumb rubber replacement ratio, the mortar also showed an increment in water absorption percentage of 10.94 % on seven days and 11.76 % on 14 days of testing. From the whole observation, water absorption rate values for this testing, sample with 3.00 % of treated crumb rubber replacement have the lowest value of water absorption percentage compared to control sample. The expanded crumb rubber has pores for every particle, and the water absorption rate becomes high because the pores keep the water, and the sample is not solid. Good mortar mixed have absorption well below 10 per cent by mass. The amount of water absorbed can be affected by the kind of material, additives, temperature, and contact period. Water absorption can also have an impact on mortar strength [13].

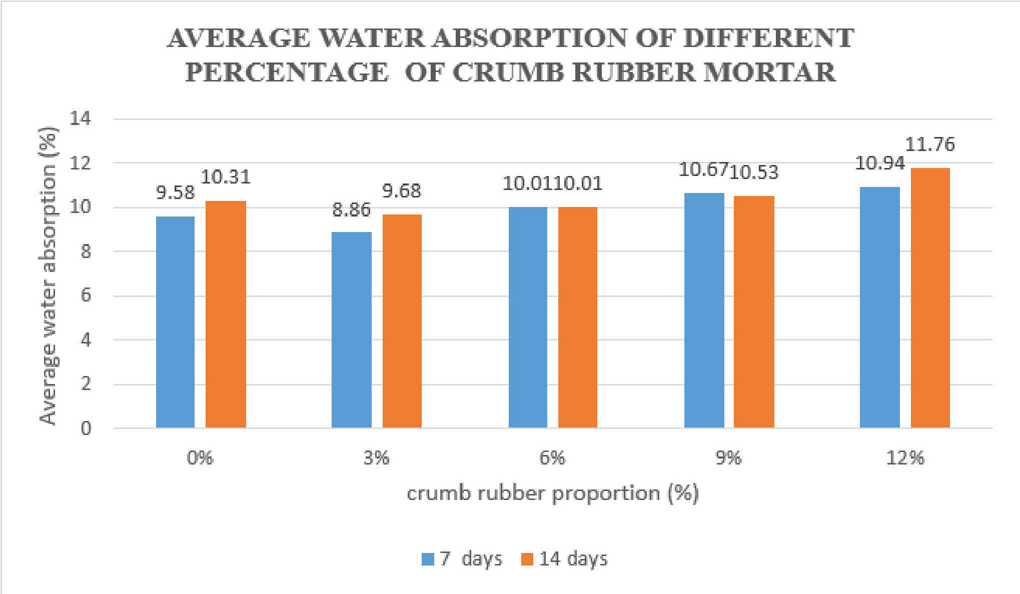

Figure 9: Average water absorption of different percentages of crumb rubber mortar

ASTM C270 is a standard specification used for mortar unit masonry. These standard addresses four types of mortar: type M, S, N, O. Each type is classified to the compressive strength of mortar. For type M mortar, the minimum compressive strength is 17.20 MPa, type S 12.40 MPa, type N 5.20 MPa, and type O is 2.40 MPa. Type M mortar is best suited for high-weight and below-grade applications such as foundations, retaining walls, and roadways. Type S mortar is often used for masonry foundations, manholes, retaining walls, sewers, and at-grade buildings such as brick patios and walkways. The next type is type N mortar which is the best choice for general use. Lastly type O mortar is ideal for repointing and other related repair work on existing structures due to its uniformity and simplicity of application. Based on Table 4, the 3.00 % and 6.00 % of crumb rubber ratios are suitable for all mortar types where they meet all the minimum compressive strength. The other 9.00 % and 12.00 % ratios are only applicable for mortar types N and O. Table below shows the result summary of compressive strength, density, and water absorption for this study. According to compressive strength and standard, the crumb rubber mortar is classified into type or mortar.

Table 4: Result summary of compressive strength, density, and water absorption test

Test	Result from experiment	Description
Compressive strength test	0% = 23.05MPa 3% = 21.63MPa 6% = 14.87MPa 9% = 9.47MPa 12% = 7.58Mpa	According to ASTM C270, minimum compressive strength - 0% is suitable for mortar type M, S, N, O - 3% is suitable for mortar type M, S, N, O - 6% is suitable for mortar type M, S, N, O - 9% is suitable for mortar type N, O - 12% is suitable for mortar type N, O
Density	0% = 1950 Kg/m^3 3% = 1900 Kg/m^3 6% = 1850 Kg/m^3 9% = 1750 Kg/m^3 12% = 1700 Kg/m^3	There is no standard for the density of mortar, but the density of mortar with crumb rubber is lower compared to the density of a mortar without crumb rubber
Water absorption	0% = 10.31% 3% = 9.68% 6% = 10.01% 9% = 10.53% 12% = 11.76%	ASTM C55-17 specifies that the regular and medium weight masonry units should have maximum water absorption of 8% and 11.3%, respectively.

4. Conclusion

This study shows the results of the different percentages of treated crumb rubber fine aggregate replacement in cement mortar. Based on the analysis outcomes, the crumb rubber is found to be able to replace fine aggregate in a mortar mixture. The use of crumb rubber can also reduce the density and weight of mortar which helps in reducing the building construction cost. Although it is crucial to have a low density of concrete mortar, according to ASTM C270 cement mortar, it is required to have a minimum net area compressive strength of 2.40 MPa for type O mortar. To specify the optimal percentages of crumb rubber waste to substitute the fine aggregate in the production of rubberized mortar without compromising the compressive strength as stated in ASTM C270, it was found that the only percentage replacement of treated crumb rubber is 3.00 % because starting from 6.00 % until 12.00 % replacement the strength of mortar has started showing a big decrement. Lastly, the treatment of crumb rubber with sodium hydroxide (NaOH) on mortar gives the crumb rubber particle a cleaner surface from dust and any other particle on the rubber surface, increasing the bonding between crumb rubber with cement paste. The immersion of rubber in sodium hydroxide solution, on the other hand, is utilised to increase the adherence of rubber to the surrounding cement paste. This increase in adhesion improves the strength of concrete containing rubber particles by increasing the surface roughness of the rubber particles on a microscopic scale [14]. After the crumb rubber was treated, it was shown that 3.00 % fine aggregate replacement give an average compressive strength of 21.63 MPa for 14 days water curing period and 3.00 % at average compressive strength of 10.59 MPa for seven days water curing period without compromising the minimum required strength as stated in ASTM C270. The density also found that when more percentage of crumb rubber replacement the density of mortar decreases. Water absorption for rubber mortar decreases at 3.00 % and 6.00 % crumb rubber replacement and increases at 9.00 % and 12.00 % replacement. It was found that the good water absorption percentage for mortar is below 10.00 %.

5. Recommendation

To enhance this research and based on personal experiences in conducting this research and the results of the experiment carried out, several recommendations are proposed:

i. The period for crumb rubber to be soaked in sodium hydroxide can be longer than 24 hours. Increasing the compressive strength value is possible because the crumb rubber is adequately treated, increasing the bonding of mortar paste and crumb rubber.
ii. Reducing the scale percentage ratio of mixture treated crumb rubber can determine the high value of compression strength with the correct optimum ratio of mortar mixture.
iii. This investigation assessed the effects of the sodium hydroxide rubber treatment method on the fine size of rubber named crumb rubber. It was revealed that this method had very positive effects of mitigating the strength drawbacks in the preparation of rubberised mortar. Accordingly, it is highly recommended to apply the introduced rubber soaking with sodium hydroxide on coarse rubber to assess its effectiveness.
iv. Considering the 7-day up to 14-day compressive strength test results, it was found that mortar gained lower strength bypassing the time. Hence, conducting a series of compressive strength tests over the long-term duration of 28 to 56 days in any future study is recommended.
v. More specific tests such as flexural bond strength, tensile test, and thermal conductivity are suggested in future studies.

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