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Properties of cement mortar containing NaOH-treated Crumb rubber as fine aggregate replacement

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Abstract. In this study, crumb rubber was used to partially replaced fine aggregate in mortar mixture by 5, 10, 15, and 20 volume percentage (vol%) with untreated and NaOH-treated crumb rubber. Thus, the total number of mixtures was 9. The mortars were tested for its flowability, compressive strength, flexural strength and density. Based on the results, increasing the replacement percentage of fine aggregate by crumb rubber reduced the compressive strength, flexural strength and density of rubberized mortar but increased the flowability. Meanwhile, the treatment of crumb rubber using NaOH solution improved the flowability, compressive strength and flexural strength. The treatment has minor effect on the hardened density of the rubberized mortar.

1. Introduction

Due to the growing number of vehicles, about 1.2 billion tonnes scrap tyres are estimated to produce globally each year by 2030, with 417 thousand tonnes estimated in Malaysia [1]. Most of scrap tyres are disposed each year and this represents a major concern worldwide. Landfilling of tyres is one of the major environmental challenges in Sabah. In fact, the Sabah government has laid out over RM700mil to improve the waste landfilling in the various districts in Sabah. Currently, the research in Sabah mainly focused on the application of waste materials such as palm oil fuel ash and rice husk ash in construction materials [2-3]

Mohammed B S and Azmi N J [4] reported that higher workability was produced when higher water to cement ratio was used due to more water available in the rubberized concrete mixes. However, it reduced the density of concrete due to the flocculation of the crumb rubber particles during mixing which resulted in the voids formation. The strength was also decreased due to the macro-porosity of the rubberized concrete, which associated with large pores and air content [4]. This demonstrates the properties of crumb rubber that repels and entrap water hence increased the air content.

Based on the review of literature by Long et. al. [5], it was established that higher replacement percentage of fine aggregates with crumb rubber reduced the workability of mortar and concrete. It was because of the rough surface of the crumb rubber which entraps the air, consequently, require more water to overcome the friction between the crumb rubber and the cement paste. However, Mohammed and Azmi [4] found the opposite with higher replacement percentage of fine aggregate by crumb rubber increased the workability of the rubberized concrete. The findings were justified by the tendency of the crumb rubber to repel water and entraps air into its surface. Therefore, the justifications for both reduction and increase of flowability are needed to be confirmed.

Previous study has shown that the increased of fine aggregate replacement with rubber reduced the density of concrete [4]. This is because when rubber was added to the concrete mixes, it increased the pores size and number due to its hydrophobicity properties [4]. High number of pores reduced the density since it was later filled with air in dry hardened state, hence lowering the density.

Similarly, the strength of rubberized mortar or concrete also reduced when higher replacement percentage was used. This was due to the lack adhesion or poor bond between crumb rubber and the binder caused by the surface of crumb rubber [6-9]. This leads to the increase distance of interfacial transition zone (ITZ) between crumb rubber and the matrix, thus promoting micro-cracks which increased in size during strength test [10]. In addition, due to low value of specific gravity, strength, stiffness and load carrying capacity of crumb rubber compared with natural sand, the strength of rubberized mortar or concrete reduced [1][7][11].

Su et al. [12] stated that smaller size crumb rubber reduced the workability due to higher water absorption of the rubber particles compared to sand, with values ranging from 4.49% to 10.70%. Thus, it reduced the free water availability for the workability. However, Bisht and Ramana [8] recorded lower water absorption with only 0.3% and claimed that the reduced workability was due to the rough surface of crumb rubber which increased the friction and high surface area. Therefore, the contradicting statements by the two authors on the causes of reduction in workability due to crumb rubber as replacement for fine aggregates needed to be investigated.

Kashani et al. [13] studied five different treatments for crumb rubber including Cement coating, Silica Fume coating, Sodium Hydroxide, Potassium Permanganate and Sulphuric acid soaking. All types of treatment had minor effect on the workability except for silica fume due to high water absorption of silica fume, consequently reduced the workability. Meanwhile, it was found that all treated crumb rubber had improved the strength of rubberized concrete. For coating method, the strength was increased due to the formation of additional calcium-silica gel [13]. On the other hand, the treatment using chemical solutions provided better contact surface between crumb rubber and the cement paste, thus increase the strength of the concrete. Kashani et al. [13] only study one replacement percentage which was 10% of fine aggregate by weight. Hence, the effect of different replacement percentage of fine aggregate using treated crumb rubber needed to be investigate.

Based on the aforementioned previous studies, there are research gaps that needed to be addressed. First, the effects and causes on the fresh and hardened properties of mortar when the percentage replacement of fine aggregates by crumb rubber is increased should be investigated. Second, to investigate on how the treatment of crumb rubber at different replacement percentage improved the fresh and hardened properties of mortar. This paper is, therefore aimed to investigate the above matters for 5%, 10%, 15% and 20% crumb rubber replacement level treated in Sodium Hydroxide solution.

2. Experiment details

2.1. Materials

The material used for the mortar mixture Ordinary Portland Cement (ASTM Type 1). Table 1 shows the physical properties of fine aggregate and crumb rubber. The crumb rubber was treated by soaking in 10 wt% (2.5 molarity) of Sodium Hydroxide (NaOH) solution for 2 hours, washed with water then dried for 24 hours. The pH value of the crumb rubber must be within range of 6 to 8 pH.

Table 1. Physical properties of fine aggregate and crumb rubber.

Material	Fine aggregate	Crumb rubber
Size, mm	0.6 – 1	0.8 – 1
Specific gravity	2.6	0.75
Water absorption, %	5	0.02

2.2. Mix proportions

The control design mix used was based on ASTM C109. The water to cement ratio used was 0.45. The fine aggregate was partially replaced by volume using untreated (as received) and treated crumb rubber with 5 vol.%, 10 vol.%, 15 vol.% and 20 vol.%. The mix proportions are shown in Table 2. The sample designation is as follows:

$$\text{T-Pr-WC} \tag{1}$$

where;

T stands for the type of treatment for mortar (M = untreated crumb rubber; T = treated crumb rubber), Pr stands for percentage of replacement (0%, 5%, 10%, 15% and 20% by volume), and WC stands for the water to cement ratio (0.45). For instance, specimen M-5-0.45 stands for mortar containing untreated crumb rubber, replacing 5% of fine aggregate by volume and 0.45 water to cement ratio.

Table 2. Mix proportion of mortar cube.

Specimen	w/c	Crumb rubber, %	Crumb rubber, g	Cement, g	Fine aggregate, g	Water, g	Additional water, g
M-0-0.45	0.45	0	0	500	1375	225	68.8
M-5-0.45	0.45	5	19.8	500	1306.3	225	65.3
M-10-0.45	0.45	10	39.6	500	1237.5	225	61.9
M-15-0.45	0.45	15	59.4	500	1168.8	225	58.4
M-20-0.45	0.45	20	79.3	500	1010	225	50.5
T-5-0.45	0.45	5	19.8	500	1306.3	225	65.3
T-10-0.45	0.45	10	39.6	500	1237.5	225	61.9
T-15-0.45	0.45	15	59.4	500	1168.8	225	58.4
T-20-0.45	0.45	20	79.3	500	1010	225	50.5

2.3 Test methods

All specimens were mixed according to ASTM C305 and tested for flowability using ASTM C1437. They were casted in 50mm x 50mm x 50mm mould, demoulded after 24 hours then cured in water curing tank for 28 days. The cured specimens were tested for compressive strength using ASTM C109, flexural strength using ASTM C348 and measured for hardened density using BS EN 1015-10.

3. Results and discussions

Table 3 below shows the results of the flowability, compressive strength, flexural strength and hardened density of the mortar. The increased in results compare to conventional mixture for corresponding water cement ratio indicated by positive (+) sign in percentage while the decreased in results indicated by negative (-) sign in percentage.

Table 3. Results of flowability, compressive strength, flexural strength and hardened density.

Mix number	Flowability, mm	+/-, %	Compressive strength, MPa	+/-, %	Flexural strength, MPa	+/-, %	Hardened Density, Kg/m^3	+/-, %
M-0-0.45	109	-	32.7	-	6.2	-	2027.2	-
M-5-0.45	115	+5.5	31.8	-2.8	6.0	-3.2	2016.8	-0.51
M-10-0.45	117	+7.3	30.8	-5.8	5.8	-6.5	2007.2	-0.99
M-15-0.45	124	+13.7	29.5	-9.8	5.5	-11.3	1985.6	-2.05
M-20-0.45	130	+19.3	27.3	-16.5	5.1	-17.7	1968.8	-2.88
T-5-0.45	116	+6.4	34.2	+4.6	6.2	-	2017.1	-0.5
T-10-0.45	120	+10.9	33.1	+1.2	6.1	-1.6	2008.2	-0.94
T-15-0.45	126	+15.5	32	-2.1	5.7	-8.1	1986	-2.03
T-20-0.45	133	+22	29.1	-11	5.2	-16.1	1968.9	-2.88

3.1. Flowability of Rubberized Mortar

Figure 1 shows the flow value of mortar mixes for treated and untreated rubberized mortar. The flowability of rubberized mixture increased with increasing crumb rubber replacement percentage. This result agreed with research by Mohammed and Azmi [4]. This is due to low water absorption of crumb rubber which is 0.02% compared to fine aggregate with 5% (as shown in Table 1). Therefore, there were more water available for the flow in the mixture of the rubberized mortar than the cement mortar.

The results also show that the treatment of crumb rubber increases the flowability of the mortar for all level of fine aggregate replacement. The treatment had smoothened the surface of the crumb rubber as shown in Figure 2, thus allowing the mixture to move easier on the surface of crumb rubber. It also shows that the structure of treated crumb rubber is similar with the river sand.

3.2. Compressive Strength of Rubberized Mortar

Figure 3 shows the compressive strength results for treated and untreated rubberized mortar. When higher replacement percentage is used, the strength is reduced due to weak bonding between rubber particles and cement matrix producing micro-cracks as shown in Figure 4. Thus, when the compressive load was applied, the crack distribution occurred very fast around the rubber particles.

On the other hand, it was also observed that the treatment of crumb rubber using NaOH increased the strength for all different percentage of replacement. The treatment provides better contact surface between the crumb rubber and the cement matrix. This is due to better bond between the treated crumb rubber and the cement matrix compared with untreated crumb rubber as shown in Figure 4. It shows that the interfacial transition zone (ITZ) is better for the treated crumb rubber because the distance between the rubber particle and the cement matrix is smaller than the untreated crumb rubber. 5% and 10% NaOH-treated rubberized mortar have better strength than the control specimen. However, at 15% and 20% of NaOH-treated crumb rubber, the strength was lower than the control specimen.

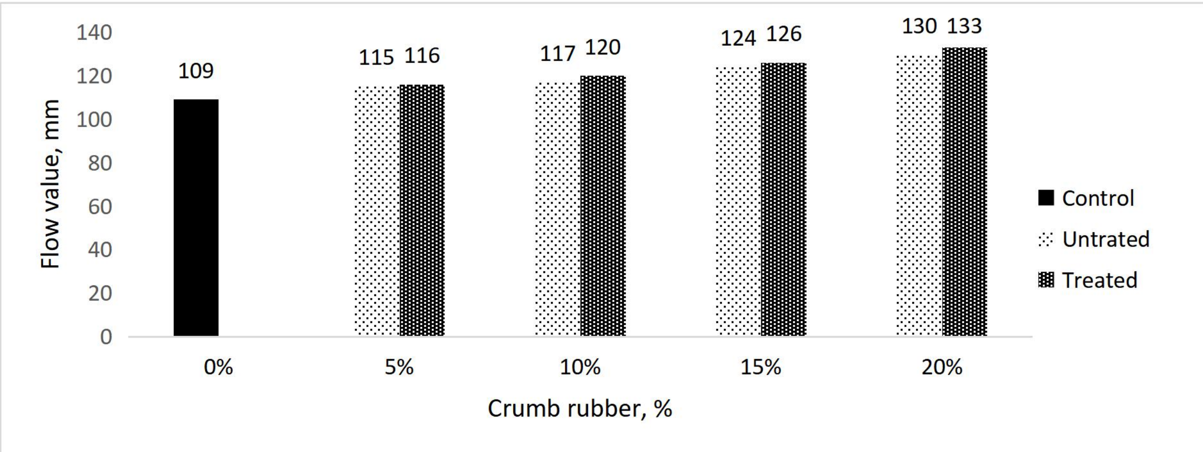

Figure 1. Flow value of mortar mixes for treated and untreated rubberized mortar.

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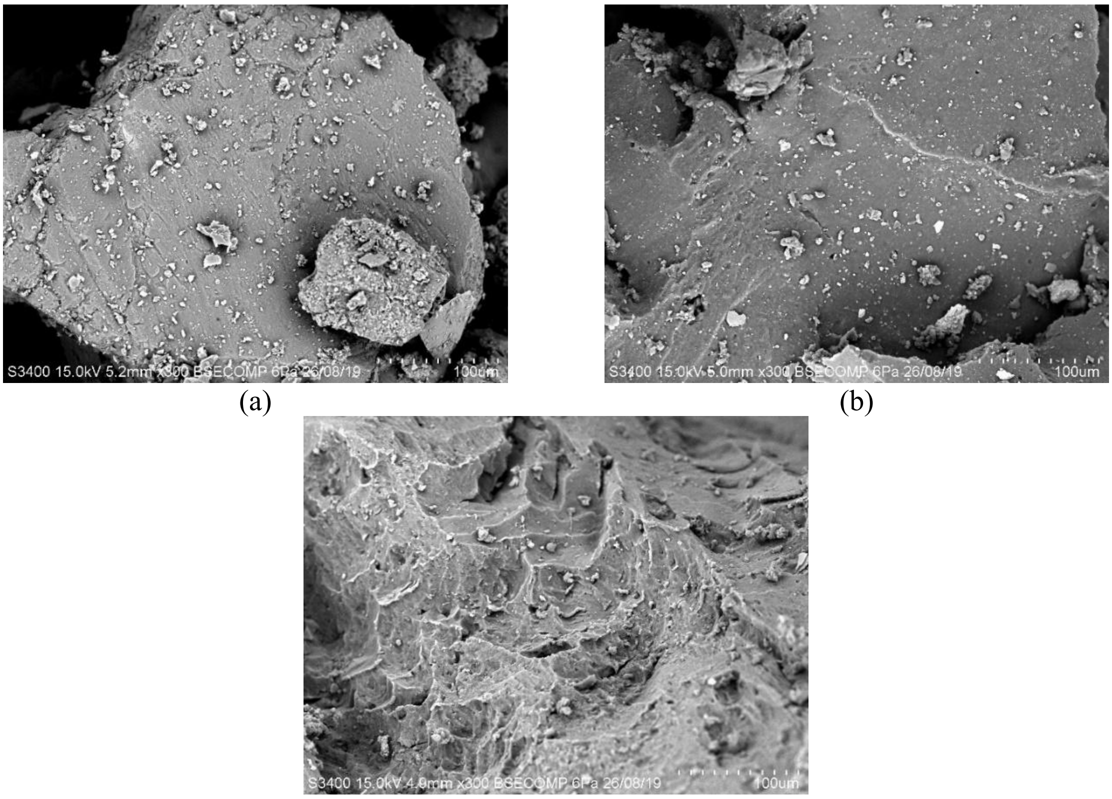


Figure 2. SEM of (a) river sand, (b) treated and (c) untreated crumb rubber particles.

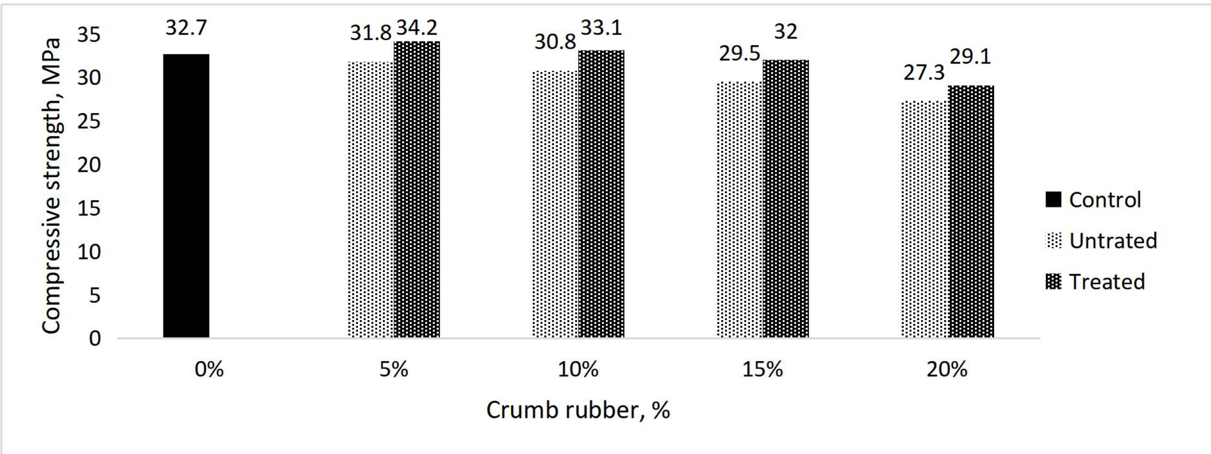
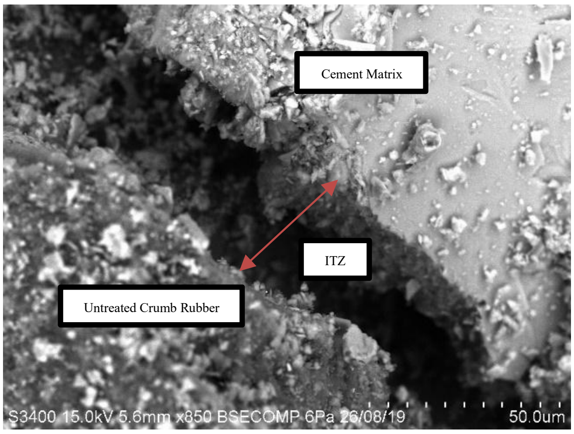
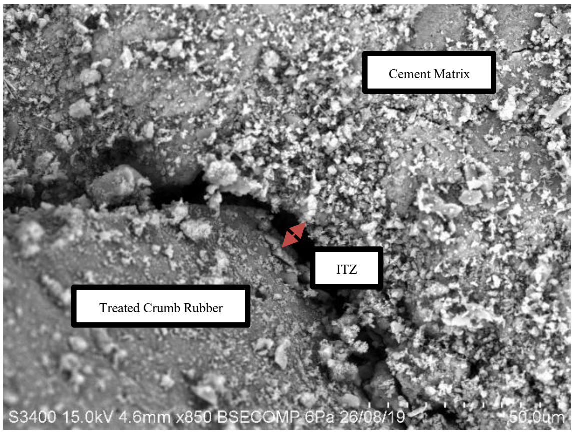


Figure 3. Compressive strength results for treated and untreated rubberized mortar.



(a)



(b)

Figure 4. SEM of (a) untreated and (b) treated rubberized mortar at 5% of replacement level.

3.3. Flexural Strength of Rubberized Mortar

Figure 5 shows the flexural strength results for treated and untreated rubberized mortar. Similar with the compressive strength results, the flexural strength decreases as the replacement with crumb rubber increases. The NaOH-treated crumb rubber improved the flexural strength of the rubberized mortar for all percentages of fine aggregate replacements than untreated crumb rubber. For 5% replacement of NaOH-treated crumb rubber, the flexural strength is the same as the control specimen.

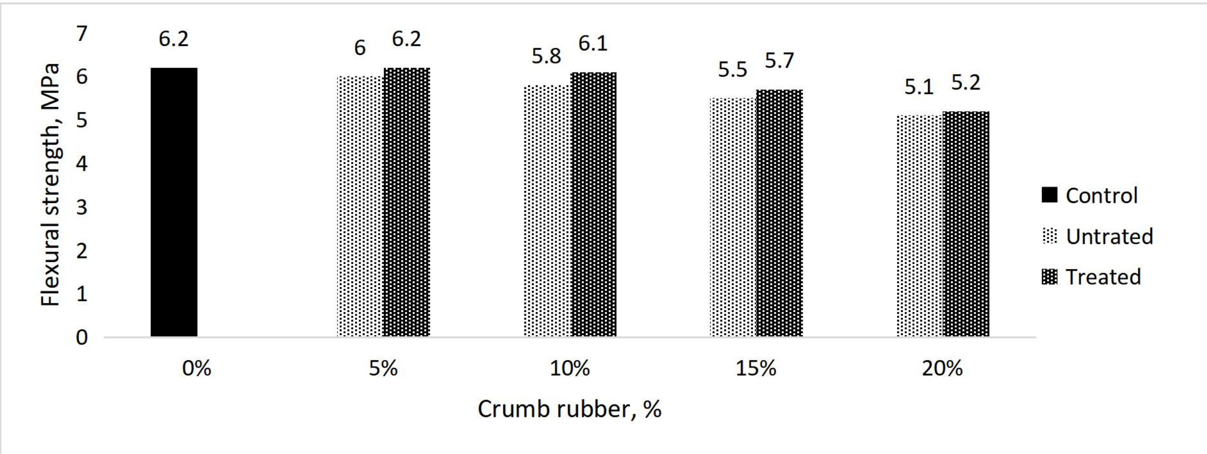


Figure 5. Flexural strength of treated and untreated rubberized mortar.

3.4. Hardened Density of Rubberized Mortar

Figure 6 shows the hardened density results for treated and untreated rubberized mortar. Higher replacement percentage reduced the hardened density of the mortar. This is due to the lower specific gravity of crumb rubber to be compared with the fine aggregate as shown in Table 1.

The treatment of crumb rubber slightly increased the density compared with the untreated crumb rubber. This is due to the better bond produced by the NaOH-treated crumb rubber as shown previously in Figure 4.

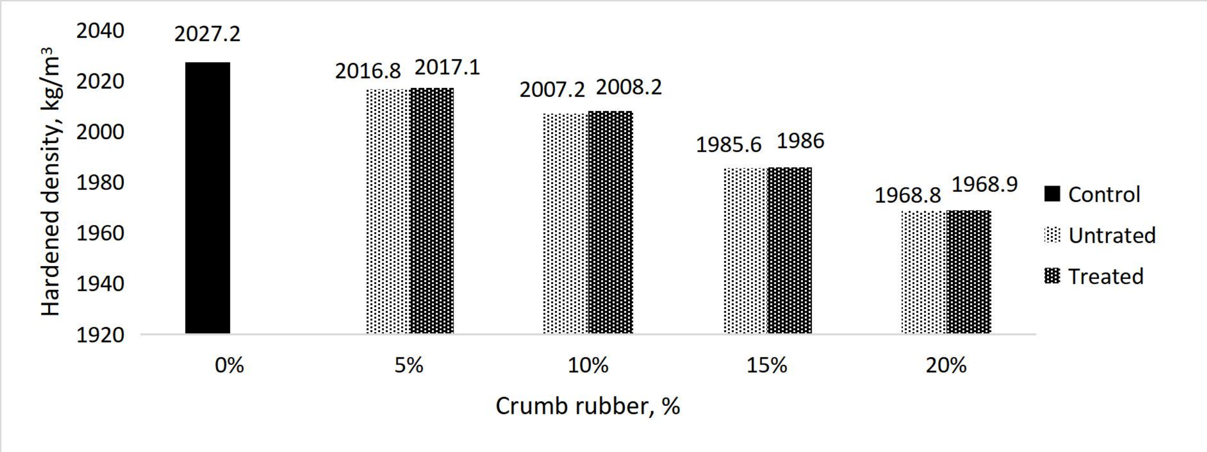


Figure 6. Hardened density results for treated and untreated rubberized mortar.

4. Conclusions

The following conclusions have been drawn from this research:

1. The flowability of rubberized mortar is increased when the replacement percentage of crumb rubber is increased, for both untreated and treated rubber. The replacement of fine aggregate using crumb rubber enhanced the workability in terms of handling, placement and finishing for the treated and untreated crumb rubber compared with the control mixture.
2. However, the density of rubberized mortar is decreased when the replacement percentage of crumb rubber is increase. This is due to the lower specific gravity of crumb rubber to be compared with the fine aggregate. The treatment did not do much in terms of density. The reduction of density can reduce the load applied in structures.
3. Lastly, the strength of rubberized mortar is reduced when higher replacement percentage of crumb rubber is used. However, the treatment of crumb rubber with NaOH improved the strength of the mortar, when compared with mortar containing untreated crumb rubber. The application of rubberized mortar can be used in low strength demand structures. \

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