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Utilization of Sodium Hydroxide (Naoh) to Treat Used Tyres as Sand Partial Replacement in Engineered Cementitious Composites

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Abstract: Engineered cementitious composites (ECC) is distinct for the tensile strain-hardening behaviour and tensile ductility contrasting to the quasi-brittle nature of ordinary concrete. The blended materials of ECC only consist of cement, sand, water, fibre, and admixture. The depleting and limited resources of sand in many countries have led to the research on alternative materials to replace sand partially or fully in the concrete mixture. Therefore, this study aims to utilize the crumb rubber (CR) in ECC as a partial sand replacement to enhance the ductility and energy dissipation capacity of the composite. The additional of CR in the ECC cause reduction of compressive strength of the composites due to its smooth surface resulting to less bonding with cement matrix. Hence, the CR is being treated with 10% sodium hydroxide (NaOH) to improve its surface roughness and enhance the adhesion between CR and cement matrix in the composites. The compressive strength results for ECC contained CR treated for duration of 2 days and 4 days were recorded. Two days is the optimum duration of CR treatment using 10% sodium hydroxide (NaOH) to lessen the reduction of the compressive strength of the rubberized engineered cementitious composites (R-ECC).

Keywords: Engineered cementitious composites (ECC), Rubberized ECC (R-ECC), crumb rubber, used tyre, sodium hydroxide (NaOH)

1. Introduction

The conventional concrete has a few issues such as high brittleness, weak in tension and susceptible to tension crack [1]. During the process to subjugate those issues, the engineered cementitious composite (ECC) had been developed [2], based on the micromechanical and fracture proposition [3]. ECC is an advanced high-performance fibre reinforced cementitious composites (HPFRCC) that exhibits tensile strain-hardening and multiple subparallel fine cracks formation that led to deformation [2]. Besides that, the ECC possesses the ability to self-consolidate stemming from the fibre bridge which activated during Serviceability Limit State (SLS) [3]. The smooth surface of the CR lead to less adhesion with the cement matrix [4] and the low strength CR replaced the high-strength aggregate lead to the reduction of concrete strength [5].

Rubberized engineered cementitious composites (R-ECC) is a group of ECC with the utilization of crumb rubber (CR) to replace fine aggregate partially or fully. The blended materials for R-ECC production consist of fine aggregate, PVA fibre, admixture, and supplementary cementitious materials. [6] had found that the rubberized engineered cementitious composites (R-ECC) can resist impact load better than normal ECC due to the improvement in the

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robustness and damage endurance. Therefore, the additional of high stiffness fibre like steel fibre can improve the compressive strength [7]; meanwhile, polyvinyl alcohol (PVA) fibre can improve the mechanical strength of the ECC due to its ability to bridge across the crack volume of the composites [8]. Furthermore, the incorporation of CR in the ECC may relieve the problems caused by the burgeoning waste scrap tyres disposal process, such as excessive dumping in the landfill and increment of carbon footprint due to the combustion process [9]. The CR can be an ideal construction material due to its ability to act as a damper under vibration as well as the ability to enhance the ductility of the composite [10].

On the other hand, a reduction in compressive strength may occur with the inclusion of CR as a partial or total replacement of aggregate in the composite. The strength reduction of the rubberized concrete mainly causes by the less bonding between crumb rubber and cement matrix [4]. The experiment done by [12] verified that the higher amount of CR used as a partial sand replacement in the ECC, the higher reduction of its compressive strength. The existence of CR may cause an increment of voids in the composites, leading to the lessening of compressive strength. The development of cracks occur fast around the crumb rubber during the loading, leading to fast fracture of the composite [4]. Moreover, CR possesses lower stiffness than sand, which may contribute to decrement in the strength of the R-ECC. Besides that, the study by [8] also found that adding CR as partial sand replacement in ECC resulted in a reduction of compressive strength owing to the capillary porosity action.

However, the addition of treated CR in the composite can lessen the reduction of the mechanical strength by enhancing the bonding between CR particles and cement matrix [11]. Hence, a significant number of prior studies have studied methods to reduce the loss in composite strength caused by rubber particles. Research by [21] demonstrated that sodium hydroxide (NaOH) solution produced the best outcome among the surface treatments that attempted to increase the hydrophilicity of the rubber surface [13]. Since NaOH solution pretreatment can create weak alkaline conditions surrounding rubber particles, the cement hydration around rubber can be enhanced when treated CR is mixed into cement concrete. Moreover, the treatment with NaOH solution improves the hydrophilicity of rubber aggregate, hence decreasing the porosity of the interface transition zone (ITZ) between CR particles and cement matrix. Consequently, rubber and cement paste adhesion might be strengthened [14]. Research by [22] had investigate the usage of 10% NaOH solution as CR pre-treatment for 20 min, 2, 24, 48 h, and 7 days. The 10% NaOH-treated CR was then incorporated into the concrete as aggregate. The study found that CR which had been treated for 24 h led to a better result on the performance of the concrete. The compressive strength of the sample with the CR that had been pre-treated with 10% NaOH for 1 day increased by 25% from the control sample.

In this study, the CR was treated with 10% NaOH solution to improve its surface roughness and enhance the adhesion between crumb rubber and cement matrix in the composites. The results for CR after treatment in the duration of 2 days and 4 days were recorded. In addition, the optimum duration of CR treatment using 10% sodium hydroxide (NaOH) to lessen the reduction of the compressive strength of the rubberized engineered cementitious composites (R-ECC) was determined.

2. Experimental Study

2.1 Materials

The binder used in this study is Composite Portland cement (CPC), while the silica sand and CR are used as aggregate in the ECC. The silica sand was obtained from L.S.K Enterprise Sdn Bhd have an average size of 1.19 mm to 0.25 mm, meanwhile CR was supplied by Kim Seng Huat Resources Sdn Bhd have an average size between 3 mm to 1 mm respectively. The CR was treated with 10% NaOH solution at different duration before blended in the mixture. The ECC is reinforced with the PVA fibre from JCT Industries Group Sdn Bhd with 6mm length. PVA fibre can provide a better bonding with the cement matrix by acting as a bridge during the crack formation, resulting in compressive strength improvement and microcrack development [15]. In addition, Superplasticizer (SP) from Sika ViscoCrete was an admixture that improves the workability of the composite during its wet state and enhances the strength in the hardened state was added in the mixture. Fig. 1 shows the image of CR and PVA fibre used in this study.

2.2 Mixture Design and Sample Preparation

A total of four mixtures of ECC were produced with the additional of 10% of CR as a partial silica sand replacement. The CR incorporated in the ECC consists of untreated (UT) and treated with 10% NaOH solution at a different duration of 2 day (T2), and 4 days (T4). The materials proportion for the ECC is shown in Table 1 which had been modified from [1]. The ratio of binder to aggregate was fixed at 1 to 0.83 from the total weight of the mixture. The water-cement ratio, volume of PVA fibre and superplasticizer (SP) were kept constant at 0.35, 1.5% by volume of the mixture and 0.89% of cement weight respectively.

The 10% NaOH solution needs to be prepared for the CR treatment before the casting process started. The CR was soaked in the 10% NaOH solution for 2 days, and 4 days. Then, the CR was cleaned to achieve (7 ± 0.5) pH before being dried at room temperature. The R-ECC preparation begins by blending the dry materials which are cement, sand, and CR to ensure uniform and thorough dispersion of constituent materials. Then pour half of the water and continue to rotate. Afterward, add SP and the rest of the water into the mixture while rotating for another 2 to 3 minutes. Finally, add PVA fibre into the blended materials as the mixing continued until a homogenous mixture was achieved. The fresh mixture was then cast in the cube moulds with 50 mm sides length immediately after the mixing process was completed and demoulded after 24 hours. After demoulded, the specimens were cured in the sealed bag at room temperature before testing.

(a) (b)

Fig. 1 - Image of (a) CR, and (b) PVA fibre

Table 1 - Material proportion of ECC

Mix	Cement	Sand	CR (%)	Water	PVA (%)	SP (%)
Control	1	0.83	0	0.35	1.5	0.89
UT	1	0.83	10	0.35	1.5	0.89
T2	1	0.83	10	0.35	1.5	0.89
T4	1	0.83	10	0.35	1.5	0.89

2.3 Methods

The compressive strength test was carried out using equipment from NL Scientific model NL 4000 X / 018U on the specimens at the age of 7, 14, and 28 days as shown in **Error! Reference source not found.**(a) and (b). Cube specimens with sides length 50 mm were used in this study as shown in **Error! Reference source not found.**(c). The specimens were removed from the sealed bag and cured in the air before being tested. The test was conducted in accordance with BS EN 196-1. The cube specimen was placed perpendicularly to the direction of load as well as centrally with respect to the lower platen. The compressive strength test was conducted at a rate 0.9 kN/s in accordance with the equipment's manual based on the size of the specimens.

(a) (b) (c)

Fig. 2 – Image of (a) (b) The compressive strength test on cube, and; (c) Cubes after compressive strength test

3. Results and Discussion

3.1 Compressive Strength

Error! Reference source not found. shows the effect of untreated CR (UT) and 10% NaOH treated CR for 2 days (T2), and 4 days (T4) on the compressive strength of R-ECC. Control specimens had achieved the highest compressive strength from age 7 days to 28 days since no CR was included in the mixture. The utilization of CR as sand partial replacement in the ECC lead to the reduction of compressive strength. However, the compressive strength of T2 and T4 were higher UT. T2 had achieved the highest strength at all ages of 7 days, 14 days, and 28 days for R-ECC specimens. UT had the lowest compressive strength might cause by the hydrophobic characteristic of CR followed by T4. Hence, 2 days of 10% NaOH treatment on CR is the ideal time duration to improve the strength of the rubberized ECC. The strength reduction of R-ECC might be due to CR's smooth surface that weaken the adhesion with the cement paste [4]. Besides that, The incorporation of CR in the ECC resulted in the reduction of strength owing to less bonding with cement paste and the lower stiffness of CR than sand [16]. [13] mentioned NaOH treated CR enhanced its bonding with the cement matrix which led to the less reduction of compressive strength supported by [16].

Fig. **1** presents the scanning electron microscopy (SEM) of mortar fracture containing untreated rubber particles and 10% NaOH treated rubber particle [17]. The 10% NaOH treated rubber had a better adhesion with the cement matrix. According to [22], the NaOH solution treatment on CR removed oil and other pollutants or chemicals that may adhere to its surface and weaken the binding as well as reduce the strength of the composites supported by [11]. The zinc stearate layer on CR which is responsible for its hydrophobic properties reacts with NaOH resulting in the soluble sodium stearate that can get rid of by washing CR with tap water as reported by Mohammadi et al. [11].

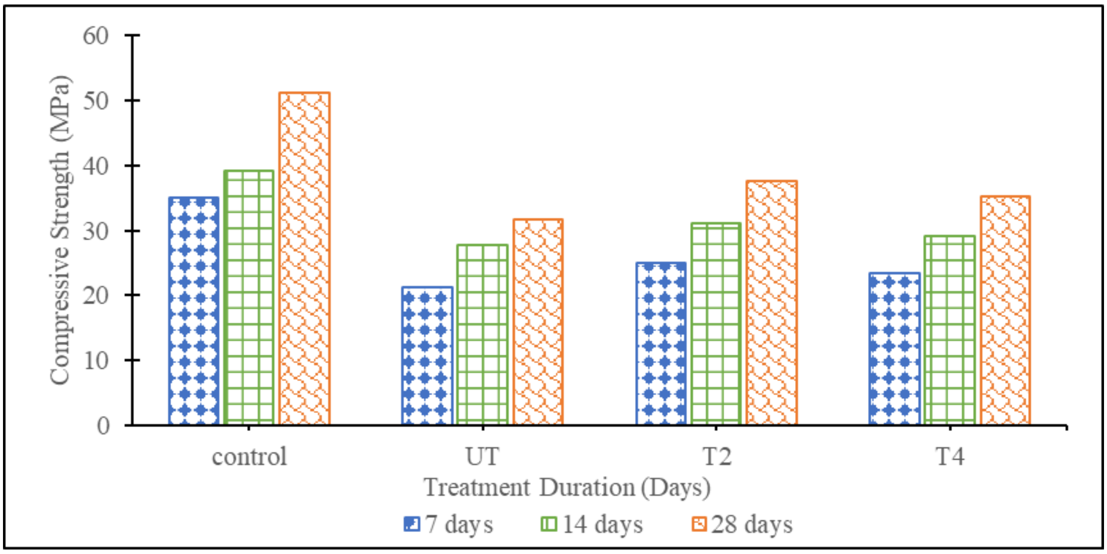

Fig. 3 - The effect of treatment duration of CR on compressive strength

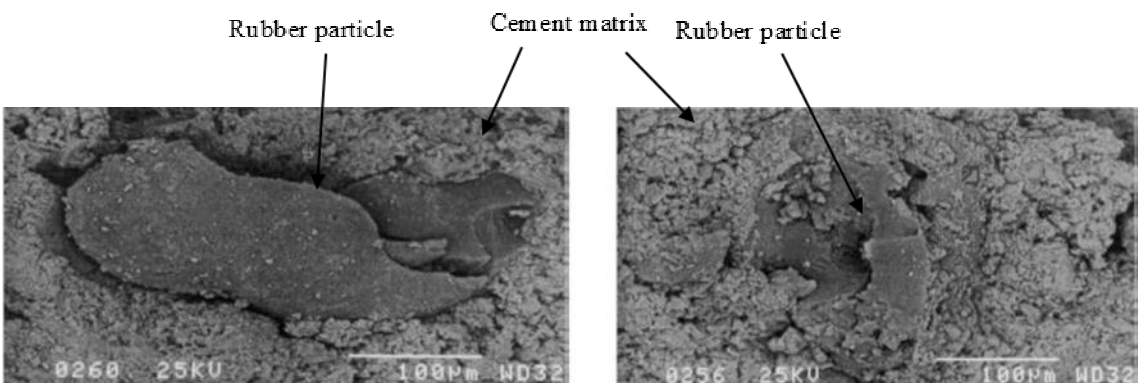

Fig. 1 - SEM images of mortar fracture with untreated rubber particles (left) and 10% NaOH treated rubber particles (right) [17]

Error! Reference source not found. presents the relative strength calculated based on Eq. (1) against the compressive strength of the rubberized ECC. The line graph shows the relative strength of the R-ECC (UT, T2, and T4) to the control. The relative strength of untreated CR (R-UT) has the lowest relative strength of 60.33% at age 7 days, 71.16% at age 14 days, and 62.04% at age 28 days compared to the relative strength of T2 (R-T2), and T4 (R-T4). This might be caused by the less bonding of the CR particles with the blended materials in the ECC due to its smooth surface. Adesina and Das reported that the reduction of the compressive strength of the R-ECC may be led by the potential weak interfacial zone between cement paste and CR [12]. Besides that, the incorporation of CR may grow the number of voids in the cement matrix, hence the nature of those void within the matrix resulting to the decreases of strength. [18] mentioned the elasticity of CR likely to weaken the bonding strength with the cement matrix which contribute to the reduction of compressive strength supported by [12]. Moreover, R-T2 and R-T4 had increased compared to the R-UT which may be contributed by the increment of the CR's surface roughness as mentioned by [19]. Based on **Error! Reference source not found.**, R-T4 had a lower percentage than R-T2 which may resulting from the 10% NaOH penetrated the CR particle and reduce its stiffness rather than eroded its outer surface [19]. Therefore, the 10% NaOH solution treatment may be an effective method to lessen the reduction of the compressive strength of the R-ECC.

$$\frac{R-ECC\,(\text{MPa})}{\text{Control }(\text{MPa})}\times 100 = \text{Relative Strength }(\%) \tag{1}$$

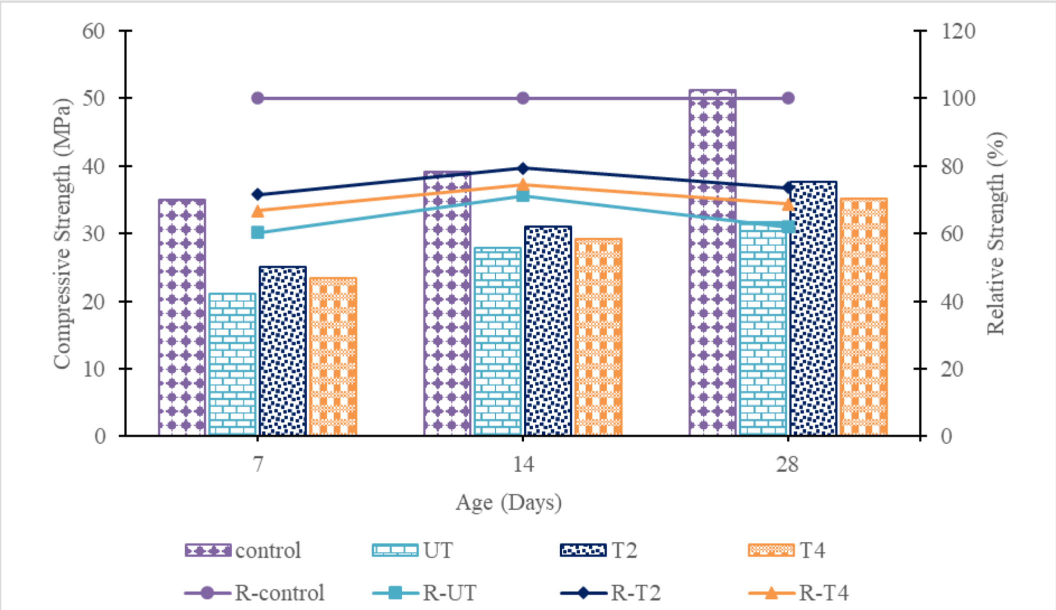

Fig. 5 - The relative strength of R-ECC

4. Conclusion

In this study, the effect of utilizing untreated and treated CR using 10% NaOH solution at different duration as partial sand replacement on the strength of the R-ECC was investigated. 10% of untreated and treated CR was used to partially replace sand in the mixture to evaluate compressive strength performance at the age of 7 days and 28 days. Based on the results obtained from the experimental study, the following conclusion can be presented:

- The incorporation of 10% CR as a partial sand replacement in the ECC resulted in a significant reduction of the compressive strength.
- The strength reduction of the R-ECC was due to the low stiffness of CR compared to the sand and the smooth surface of CR, which led to less adhesion with the cement matrix.
- The R-ECC with the 10% NaOH solution treated CR had achieved a higher compressive strength than the R-ECC with the untreated CR. NaOH solution reacted to the zinc stearate layer on the CR surface, making it hydrophilic and improving its surface roughness.
- On the other hand, the longer the duration of CR treated with the 10% NaOH solution can cause a reduction of strength owing to the NaOH that penetrated the CR, which leads to a decrease in stiffness rather than improving its surface roughness.

This study investigated the strength performance of R-ECC having a different duration of 10% NaOH solution-treated CR. In subsequent work, a few recommendations can be made:

- Utilized a few different concentrations of NaOH solution to treat CR.
- Extend the study to other mechanical properties such as flexural and tensile strength.

- Study the physical properties of the CR using scanning electron microscopy (SEM).

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