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WORKABILITY INVESTIGATION ON THE FRESH MIX OF ECC MORTAR AND CRUMB RUBBER (CR)-ECC BASED ON VARIATIONS OF PALM SHELL ASH, RIVER SAND, AND CEMENT

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Abstract

Engineered cementitious composite (ECC) is a composite that has better tensile properties and behavior than concrete. ECCs are usually made of cement, water, silica sand, cementitious materials, fibers, and other additives. The term ECC mortar is used because the ECC does not use fiber. The cementitious material in this research uses palm shell ash, with a proportion of 5%, 10%, and 15% of the cement weight. As a replacement for the fiber, crumb rubbers are used, with proportions of 2.5%; 5%; 7.5%; 10% and 12.5% of the cement weight. Workability was measured based on slumpflow tests (with measurements T500 and slumpflow diameter). The objective of this study is to establish the workability of fresh mix of the ECC mortar and CR-ECC with variations in the addition of palm shell ash, cement, sand and crumb rubber. Based on the results of slumpflow tests, the average diameter for fresh ECC mortars ranges between 88 cm to 106.5 cm, and the T500 ranges from 0.28 seconds to 1.39 seconds. As for fresh CR-ECC mix, the mean slumpflow diameter is between 71 cm to 93 cm and the T500 ranging between 0.90 seconds and 1.68 seconds. All of these values meet the slumpflow requirements stipulated by EFNARC. Nevertheless, the workability of the fresh mix ECC mortar is more flowable than the fresh mix CR-ECC. This is because crumb rubbers are water-absorbing.

Keyword: ECC, cementitious materials, palm shell ash, crumb rubber, workability

Introduction

Use of concrete in Indonesia is the most widely used construction material because concrete has some advantages, including that the materials are easy to obtain, easy to implement, fire resistant and having a high compressive strength. Concrete is a type of composite commonly used in construction which is made from a mixture of water, cement, fine aggregates (sand), and coarse aggregate (usually gravel or crushed stone) with a certain proportion, which forms a solid mass. Apart from having advantages, concrete also has disadvantages, including low tensile and flexural strength, causing the concrete to crack easily and also low ductility, especially in earthquake-resistant structures.

Concrete researchers continue to make innovations and technological developments in making efforts to improve the quality and strength of concrete. One effort to improve the quality and strength of concrete is to use engineered cementitious composites (ECC), which is a composite that does not use coarse aggregate.

The building sector has become more environmentally conscious and sustainable. Because of its resilience to cracks, ductility, strength capacity, and self-healing ability,

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ECC is one of the sustainable and environmentally friendly technologies that have the potential to reduce the built environment's carbon and energy footprints. An attempt has been made throughout the last 20 years to employ fibers, fillers, and binders that are more environmentally friendly in order to produce an ECC that is greener (Al-Fakih et al., 2021; Hau Hong et al., 2020; Shoji et al., 2022). These initiatives fit under a number of categories.

ECC was first discovered by Victor C. Li in the early 1990s at Michigan University, USA. Li et al. (1993) and Li (1993) developed ECC based on micromechanical principles, fiber crack bridging behavior, multiple cracks, and apparent strain hardening. In developing ECC, fundamental approaches generally aim to produce reciprocal mechanical interactions between fiber, matrix, and fiber-matrix interface, as well as to increase ductility and tensile strength. The fiber content will be 2% or less based on volume fraction (Li, 1993, 2008). High volume fly ash and micro-silica sand are always utilized to support the unique behavior of ECC. The adjusted SP is used to control the workability of ECC (Wang & Li, 2007). Due to its adverse impact on the unique behavior of the composite, coarse aggregate is not used in ECC mixtures. In general, the ECC composition consists of a water-cement ratio and a sand-cement ratio of 0.5 or lower, where the cement content is less than 600 kg/m3. Apart from that, the typical fiber used is polyvinyl alcohol (PVA), but other fibers can also be used such as high strength polyethylene (PE) fiber or polypropylene (PP) fiber (Fischer & Shuxin, 2003; Li & Wang, 2002). The main mechanical properties of ECC are shown in Table1 (Li, 2008).

Table 1. The main mechanical properties of ECC (Li, 2008)

Compressive Strength	Fist Crack Strength	Ultimate Tensile Strength	Ultimate Tensile Strain	Young's Modulus	Flexural Strength	Density
(MPa)	(MPa)	(MPa)	(%)	(GPa)	(MPa)	(kg/m³)
20-95	3-7	4-12	1-8	18-34	10-30	950-2300

Aswin et al. (2024) has developed ECC using local river sand, silica fume, medium to high-volume fly ash (FA) and polyvinyl alcohol fiber (PVA), by evaluating workability and strong pressure at test life (1, 7, 28, 60, and 180 days). All ECC samples had a strong pressure of more than 20 MPa after 1 day, while the strongest pressure after 28 days was 111.28 MPa.

Liew et al. (2020) revealed that ECC fresh mix must have high workability. However, the use of volume fraction of PVA fiber causes a decrease in workability. This is due to the hydrophilic nature of PVA fiber. This deterioration is clearly seen when the volume fraction reaches 2% or more. Furthermore, Zhao et al. (2023) reported that the use of fly ash and crumb rubber in the ECC mix results in increased ductility, a denser fracture pattern, and decreased permeability.

Global cement production exceeds 4 billion tons per year, accounting for around 8% of CO2 emissions (Lehne & Preston, 2018; Summerbell et al., 2016). Thus, the purpose of this study is to investigate the fresh performance and workability of ECC mix with a low cement content (less than 400 kg/m3) and the creation of a green ECC by the utilization of waste materials like crumb rubber and palm shell ash.

A study of the workability of the ECC mortar and crumb rubber ECC mix is important, because the target for using ECC mix in the field is that fresh ECC mix can flow and consolidate itself without using a vibrator. In this study, the workability of fresh ECC mix was only considered based on the slump flow diameter and T500 only. Apart from that, the differences in workability that occur between fresh ECC mortar mix and the ECC fresh mix using crumb rubber (CR-ECC) will also be evaluated.

Research Methods

Materials and Equipment

Preparation of materials and equipment can be used to make or form ECC and CR-ECC mortars are cement, water, sand, palm shell ash, superplasticizer and crumb rubber. The cement used is OPC with Type-1. Palm shell ash is obtained from plantations in Serdang Bedagai Regency, North Sumatra Province which is produce from the burning process and only uses palm shell ash that passes filter no. 30 or 0.6 mm diameter. Furthermore, the procurement of equipment used in making ECC mortar is scales, mixer drills, slump test equipment, flowability test equipment, measuring meters, etc.

Mix Design

Mix design is the process of determining the right proportion (composition) to achieve the desired properties in a mixture or mortar in order to produce a mixture that meets the desired technical requirements. In this research, mix design was carried out using the addition of crumb rubber material and without crumb rubber. The composition of the mixture without crumb rubber is coded Type-1, namely AME, EM, TEM, and the composition of the mixture with crumb rubber is coded Type-2, namely FRC, CRE, TCRE.

The mix proportion of ECC mortar (Type-1: AME, EM, TEM) is made based on trial and error in the lab, as well as referring to related references. Meanwhile, the Crumb Rubber ECC mix proportion (Type-2: FCR, CRE, TCRE) is taken with the ECC mortar mix proportion which produces the highest compressive strength value. The ECC mortar mix proportion can be seen in Table 2, and for CR-ECC is shown in Table 3.

Table 2. Mix Proportion of ECC Mortar

Code Specimen	Cement (kg)	Ash Shell Palm (kg)	Water (kg)	Sand (kg)	Super plasticizer (kg)	Crumb rubber (kg)
AME 0%	10.720	-	4.449	11.792	0.075	-
AME 5%	10.467	0.523	4.344	11.513	0.167	-
AME 10%	10.239	1.024	4.249	11.263	0.256	-
AME 15%	10.011	1.502	4.155	11.012	0.34	-
EM 0%	10.382	-	4.360	10.382	0.073	-
EM 5%	10.134	0.507	4.256	10.134	0.162	-
EM 10%	9.898	0.99	4.157	9.898	0.247	-
EM 15%	9.673	1.451	4.063	9.673	0.329	-
TEM 0%	10.275	-	4.624	10.275	0.072	-
TEM 5%	10.034	0.502	4.515	10.034	0.161	-
TEM 10%	9.803	0.98	4.411	9.803	0.245	-
TEM 15%	9.583	1.437	4.312	9.583	0.326	-

Table 3. Mix Proportion of CR-ECC

Code Specimen	Cement (kg)	Ash Shell Palm (kg)	Water (kg)	Sand (kg)	Super plasticizer (kg)	Crumb rubber (kg)
FCR 0%	10.239	1.024	4.249	11.263	0.256	-
FCR 2,5%	10.149	1.015	4.212	11.164	0.254	0.254
FCR 5%	10.043	1.004	4.168	11.047	0.251	0.502
FCR 7,5%	9.996	0.996	4.134	10.957	0.249	0.747

Code Specimen	Cement (kg)	Ash Shell Palm (kg)	Water (kg)	Sand (kg)	Super plasticizer (kg)	Crumb rubber (kg)
FCR 10%	9.866	0.987	4.094	10.852	0.247	0.987
FCR 12,5%	9.779	0.978	4.058	10.757	0.244	1.222
CRE 0%	9.898	0.99	4.157	9.898	0.247	-
CRE 2,5%	9.802	0.980	4.117	9.802	0.245	0.245
CRE 5%	9.707	0.971	4.077	9.707	0.243	0.485
CRE 7,5%	9.615	0.961	4.038	9.615	0.240	0.721
CRE 10%	9.524	0.952	4.000	9.524	0.238	0.952
CRE 12,5%	9.435	0.944	3.963	9.435	0.236	1.179
TCRE 0%	9.803	0.98	4.411	9.803	0.245	-
TCRE 2,5%	9.709	0.971	4.369	9.709	0.243	0.243
TCRE 5%	9.615	0.961	4.327	9.615	0.240	0.481
TCRE 7,5%	9.524	0.952	4.286	9.524	0.238	0.714
TCRE 10%	9.435	0.944	4.246	9.435	0.236	0.944
TCRE 12,5%	9.347	0.935	4.206	9.347	0.234	1.168

The Fresh Mix of ECC Mortar and Crumb Rubber-ECC

All related ingredients are mixed in a dry container, then stirred thoroughly until the desired mixture consistency is achieved. The mixing process usually takes about 10-12 minutes. Then the fresh mixture of ECC mortar or CR-ECC is put into the Abrams cone and lifted slowly. Next, the flowability time (T500) and the average diameter of the fresh mix distribution were measured. The procedure for implementing the workability test can be seen in Figure 1.

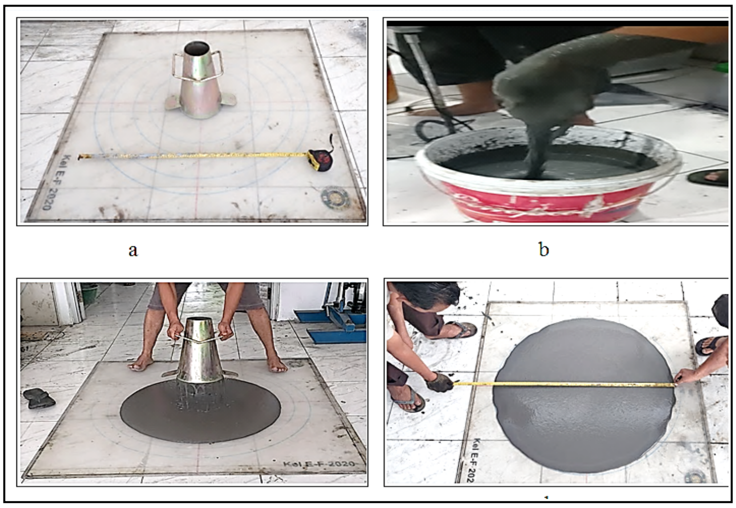

Figure 1. Workability test of the fresh ECC mortar and CR-ECC mix

Results and Discussion

Based on the results of workability testing on the fresh ECC mortar mix (Type-1: AME, EM and TEM) and CR-ECC mix (Type-2: FCR, CRE and TCRE), the flowability value T500 and the average slumpflow diameter are obtained, as shown in Figure 2-5.

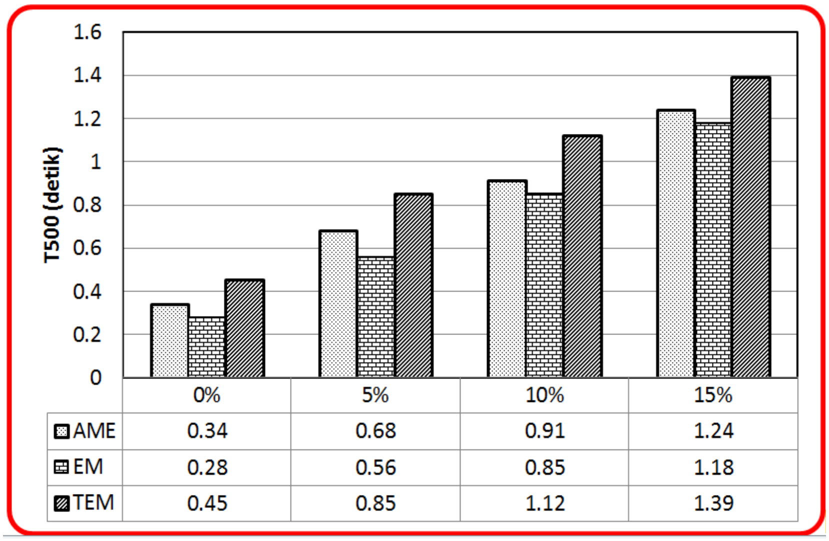

Figure 2. Slumpflow T500 of fresh ECC mortar

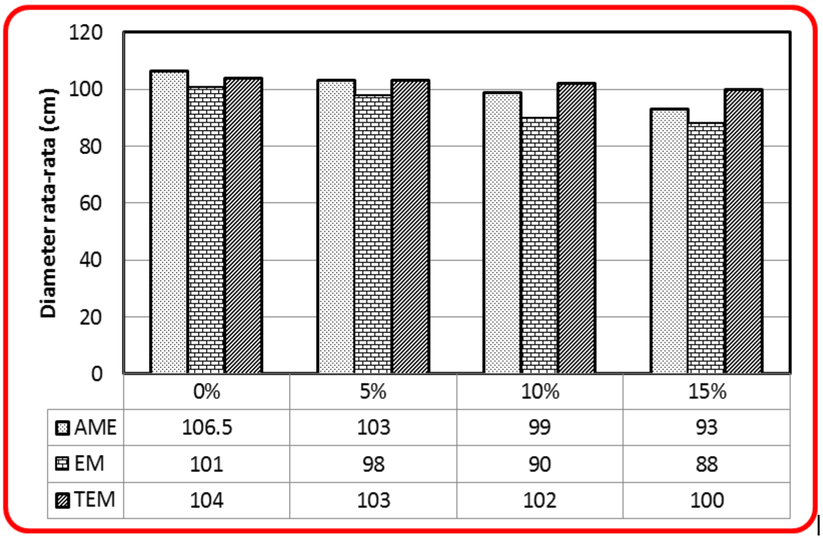

Figure 3. Slumpflow diameter of fresh ECC mortar

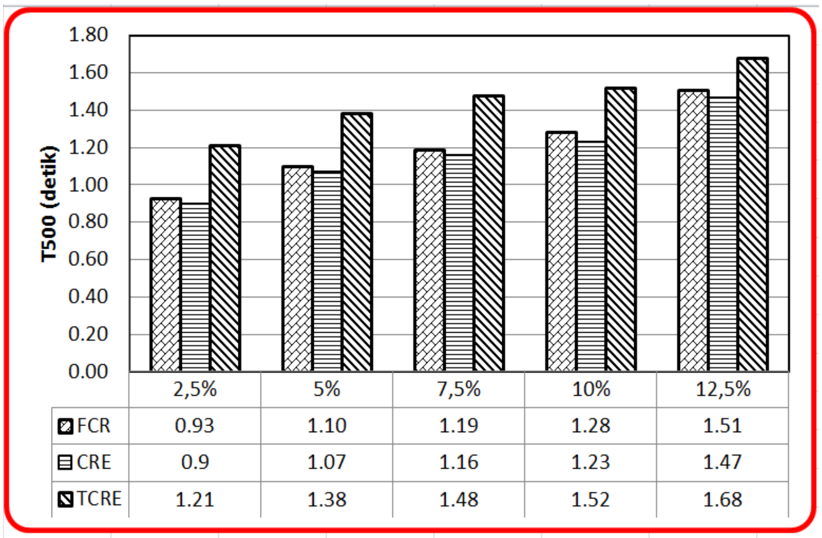

Figure 4. Slump flow T500 of fresh CR-ECC mix

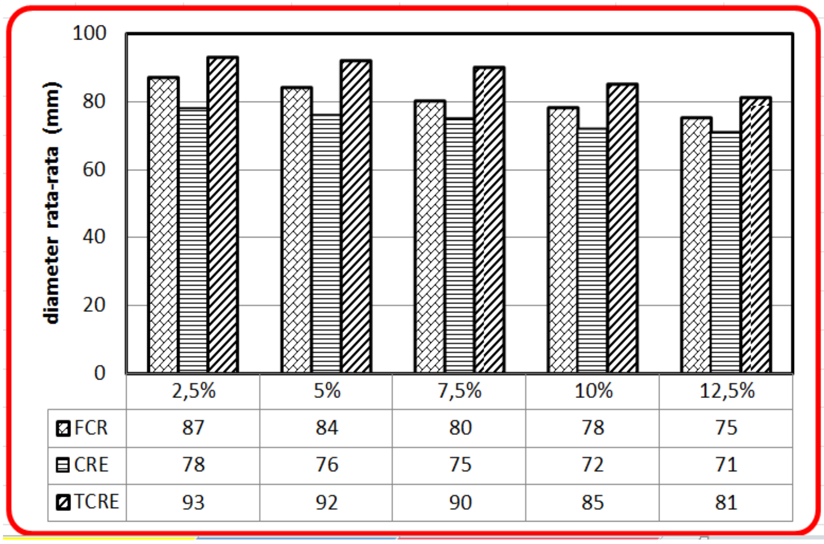

Figure 5. Slump flow diameter of fresh CR-ECC mix

Based on the workability test results, it can be seen that all fresh ECC mortar mix and CR-ECC mix showed the good workability, and are in accordance with the provisions of EFNARC. However, the workability of fresh ECC mortar is more flowable than fresh mix of CR-ECC. This is because crumb rubber absorbs water.

Conclusion

The workability of the fresh ECC mortar is better than the fresh mix of CR-ECC. This is because the CR-ECC contains the crumb rubber which absorbs water, thus causing a reduction in the workability value of the fresh CR-ECC mix.

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