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Rubberised Engineered Cementitious Composite (R-ECC) As Retrofitting Material for Reinforced Concrete Beam-Column Joint Subjected to Cyclic Loading

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Abstract **— Earthquakes present significant risks to infrastructure and human safety, highlighting the need for effective disaster mitigation strategies. This study explores the utilization of scrap rubber tires as a partial replacement for aggregate in concrete. The primary objective is to analyze the load-displacement behavior and structural performance of RC beams before and after retrofitting with Rubberized Engineered Cementitious Composite (R-ECC) under fatigue loading. The testing procedure included static and fatigue load assessments using a four-point bending test. The retrofitting process incorporated 5% R-ECC. Findings indicate that R-ECC retrofitting improves concrete's ductility, load-displacement response, and flexural fatigue strength, resulting in greater displacement capacity and increased deformation before failure.**

Keywords—Rubberized Engineered Cementitious Composite (R-ECC), Engineered Cementitious Composites (ECC), Crumb rubber, Sodium Hydroxide (NaOH), Tyres.

I. INTRODUCTION

Engineered Cementitious Composites (ECC), also known as strain-hardening cement-based composites (SHCC), are a specialized type of high-performance fiber-reinforced concrete (FRC). ECC exhibits exceptional ductility under tensile loads, achieving a strain capacity exceeding 3% with a fiber volume of less than 2%. As stated by Sakulich and Li [1], this strain capacity is significantly higher than that of conventional concrete, allowing ECC to overcome the brittle nature typically associated with traditional concrete and fiber-reinforced concrete. The ability of ECC to form multiple micro-cracks instead of a single major fracture contributes to its superior tensile performance. Additionally, once the strain reaches 1%, the crack width remains consistently below 100 µm. This intrinsic crack control mechanism enhances the material's durability against mechanical, chemical, and thermal stresses, making it highly suitable for long-lasting infrastructure [2]. In response to the growing need for materials that support large-scale structural developments, high-strength and high-ductility ECC has been developed.

ECC's unique properties make it an ideal construction material for improving structural resilience, durability, and resistance to damage. During its development, controlling the rheology of the fresh mixture was a key aspect to ensure proper fiber dispersion. More importantly, matrix toughness had to be adjusted so that multiple cracks could form before the fiber bridging capacity was exceeded. In this study, coarse aggregates were replaced with crumb rubber, and other key materials such as Polyvinyl Alcohol (PVA) fibers, superplasticizers (SP), and fly ash were incorporated into the ECC mixture [3].

Murali *et al.* [4] highlighted that discarded tires are often burned, causing environmental harm. A more sustainable alternative involves repurposing waste rubber as a partial substitute for fine aggregates in concrete. This research focuses on the durability of

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ECC with a high volume of crumb rubber, specifically its resistance to chemical exposure. Alaloul *et al.* [3] also noted that the growing number of discarded rubber tires poses a significant environmental challenge. Using recycled rubber as a partial aggregate replacement in materials like bitumen and concrete offers a solution to minimize environmental damage compared to harmful disposal methods. However, the application of crumb rubber in ECC remains a topic of ongoing scientific investigation and debate.

The flexural behavior of R-ECC in reinforced concrete beams was analyzed at different cross-sectional locations, including compression and tension zones. Rubber particles of varying sizes were used in the R-ECC mixture. Research by AbdelAleem and Hassan [5] on the structural behavior of beams retrofitted with R-ECC revealed that applying an R-ECC layer on the compression side significantly improved deformability, cracking resistance, ductility, and energy absorption compared to standard concrete beams. However, beams retrofitted on the tension side demonstrated lower ductility and energy absorption than those strengthened on the compression side, though they still outperformed conventional concrete beams. The findings also showed that applying an R-ECC layer containing powder rubber on the compression side enhanced ductility and energy absorption more effectively than using crumb rubber.

Southeast Asia has experienced numerous major earthquakes, leading to varying levels of structural damage. In Malaysia, most earthquakes have caused only minor structural cracking, but seismic activity originating in Sabah, such as the Ranau Cluster earthquake, poses a potential risk. Indonesia has suffered some of the world's most destructive earthquakes, with widespread damage to buildings and infrastructure. Similarly, in the Philippines, approximately 90% of seismic events have resulted in significant structural damage. Many earthquakes in these regions occur at intermediate to deep depths, leading to extensive destruction. Additionally, seismic activity in Indonesia, the Philippines, and Myanmar has triggered secondary disasters, including tsunamis, volcanic eruptions, and landslides. For instance, the 2015 M6.0 Ranau earthquake led to landslides and mudslides in Sg. Mesilou, resulting in fatalities and infrastructure damage [6].

This research aims to examine the load-displacement behavior of reinforced concrete (RC) beams retrofitted with R-ECC when subjected to fatigue loading. Additionally, the study assesses the structural performance of RC beams before and after retrofitting with R-ECC to evaluate its potential in improving structural durability and seismic resistance.

II. METHODOLOGY

A. Preparation of Beam

For sample preparation, a standard reinforced concrete beam was used, with a conventional concrete mix proportion. A total of three samples were prepared for testing, utilizing concrete of grade C30.

The reinforcement layout included steel reinforcements along the compression and tension faces, as well as shear reinforcements in the form of either bent longitudinal bars or vertical stirrups. The reinforcement details of the beam are illustrated in Fig. 1. In this experiment, 10T reinforcement bars were used, and the beam had a span of 1000 mm. The dimensions of the RC beam were 1000 mm × 220 mm × 220 mm, with a target compressive strength of 30 MPa. Additionally, the characteristic strength of concrete was 30 kN/m, while the characteristic strength of steel was 500 kN/m.

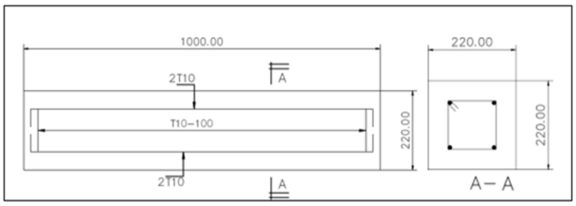


Fig. 1. Detailing of the beam.

The beam samples were constructed using reinforced concrete, serving as structural elements capable of withstanding transverse external loads. These loads generate torsion, shear forces, and bending moments along the beam's length. While concrete exhibits high compressive strength, it has relatively low tensile strength.

The next stage of the study involved the casting process for the concrete models. The concrete used in this experiment was grade C30. The initial phase of casting an RC beam included design and preparation, where the required dimensions, reinforcement details, and load-bearing capacity were determined based on structural design requirements. The casting process of the RC beam is illustrated in Fig. 2.

Formwork was prepared to shape the beam, ensuring that reinforcement was accurately positioned with adequate concrete cover and proper spacing. Tie wires or rebar chairs were used to secure the reinforcement in place. The concrete mix was prepared by combining cement, aggregates (sand and coarse aggregates), and water in the correct proportions. A concrete mixer was used to blend the materials thoroughly until a uniform consistency was achieved.

Once mixed, the concrete was gradually poured into the formwork to maintain uniformity and prevent segregation. To eliminate air voids and ensure proper compaction, vibrators and other suitable tools were used. Throughout the entire volume of the beam, adequate compaction was maintained. Afterward, the exposed concrete surface was finished using a trowel or float to achieve a smooth appearance. The samples were then cured for 28 days, with sufficient moisture maintained throughout the curing process. Finally, the beam was inspected for defects or irregularities, and any necessary corrections were made as required.

(a) Molds of RC Beam
(b) Concrete pouring into the formwork
(c) Vibrating Concrete Process
(d) Flatten the surface of the RC Beam

Fig. 2. Casting process of RC beam.

B. Experimental Work

After cured the samples were tested proving static load and harmonic fatigue load. A roller and pin were employed in a four-point loading setup to give a simply supported boundary condition. The actual span of the beams was 1 meter. Figure 3 shows the RC beams during the four-point test and Fig. 4 shows the experimental work of RC beam.

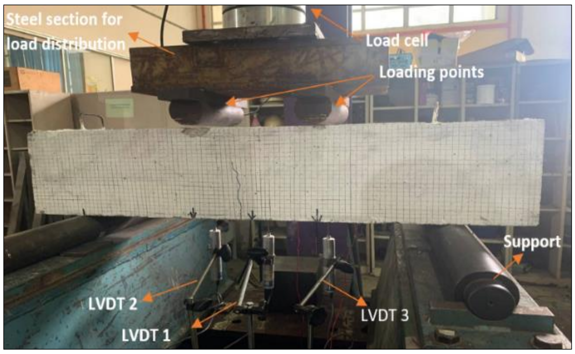


Fig. 3. RC beams during the Four-Point Test.

The 225 kN hydraulic jack was used to load the beams at a rate of 0.02 mm/min. To measure the deflection, a linear variable differential transformer (LVDT) was employed and installed in the middle span of the beams. All samples were tested up until the point at which the imposed load began to decrease and the middle span's maximum displacement was reached. At every load increment up until the beam failed, the failure manner of the beam was visually inspected, and the cracks were identified and recorded [7]. Figure 4 shows the harmonic fatigue regime.

Harmonic fatigue tests were run and referred to the repetitive loading of a structure at a constant frequency, which can lead to fatigue failure over time. When considering a reinforced concrete RC beam, a harmonic fatigue load regime typically involves subjecting the beam to cyclic loading at a specific frequency. The load can be applied either as a static load with a dynamic component or as purely dynamic loading. The failure of RC beams under fatigue stress was caused by reinforcement yielding in the tension zone and concrete crushing in the compression zone. The fatigue strength of a beam was determined by how many fatigue cycles it could withstand. The LVDTs recorded the deflection at the mid-span and quarter span owing to crack development after the cracks formed and closed after one cycle of fatigue loading. The quick shift in the mid-span deflection causes the beam's flexural stiffness to decrease.

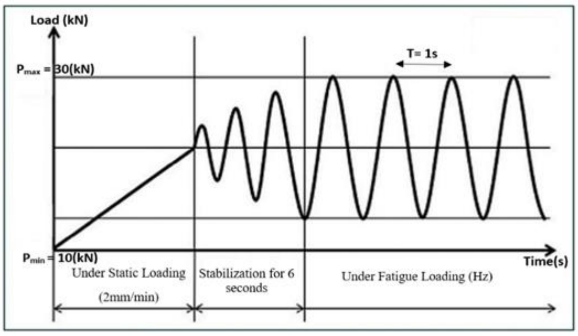
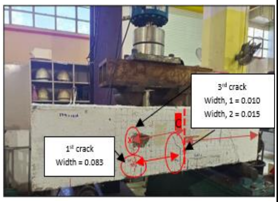


Fig. 4. The Harmonic Fatigue Load Regime.

Lastly, analysis of data for a reinforced concrete beam to assess its structural behaviour and performance. Load analysis determined the applied loads on the beam, such as dead loads, live loads, and any other relevant forces or moments. Material properties gather information about the properties of the concrete and reinforcing steel used in the beam, including compressive strength, tensile strength, modulus of elasticity, and yield strength.

C. Beam Retrofitting Work

After that, retrofitting with 5% of R-ECC. Crumb rubber was a material that replaced sand with rubber particles when mixing concrete [8]. Fly ash was used as a replacement Portland cement for RC beams. Polyvinyl alcohol (PVA) is a nontoxic and thermoplastic polymer and biodegradable and harmless. Polyvinyl Alcohol (PVA) can be used to create composite materials because of its outstanding mechanical and thermal properties and improved interfacial adhesion with reinforcing materials like fibers Set of ECC specimens was prepared, and ECC and crumb rubber, where cement replacement with fly ash (by weight) was evaluated for each experimental series (5% for crumb rubber ECC series). In the crumb rubber ECC experimental series, sand was replaced with crumb rubber (by volume). Figure 5(a) shows the beam crack after the test. The crack portion was cut and removed using grinding and a hacker machine as shown in Figs. 5(b) and 5(c). Meanwhile, Fig. 5(d) shows the sample after cutting and removing portion. After cutting and removing the crack portion, the sample was cast and retested after retrofitting as shown in Figs. 5(e) and Fig. 5(f).



(a) The Beam Crack After Test

(b) Cut and Remove the Cracked Portion Using Grinding Machine

(c) Cut and Remove the Cracked Portion Using Hacker Machine

(d) The Sample of RC Beam After Cut and Remove the Cracked Portion

(e) The Casting of Samples 2 and 3 After Retrofitted with Rubberized Engineered Cementitious Composite (R-ECC)

(f) The Sample 2 of RC Beam After Retrofit with Rubberized Engineered Cementitious Composite (R-ECC)

Fig. 5. Experimental work of RC beam.

D. Preparation of Rubberized Engineered Cementitious Composite (R-ECC)

A study by Aziz *et al.* [8], preparation retrofitting work used of 5% for crumb rubber ECC series. In the crumb rubber ECC experimental series, sand is replaced with crumb rubber by volume. The 10% NaOH solution must be prepared for CR treatment before the casting procedure. 1 L of distilled water was heated with 400 g of NaOH granules, and the mixture was stirred until it turned clear. After that, the heat was turned off, and the mixture was stirred continuously for two to three hours to let it cool. Once the CR container has been fully submerged in the 10% NaOH solution, let it sit for 1 day, 2 days, and 3 days. Afterwards, the crumbs were rinsed thoroughly with wash with tap water until it reached 7 ± 0.5 pH. The crumbs were dried at normal temperature. The mixing of all materials was done conventionally using a Hobart mortar mixer. Initially, the dry ingredients (crumb rubber, fly ash, sand, and Composite Portland Cement) were added to the mixing bowl and mixed. Half of the water and superplasticizer were added and mixed. The remaining water and Polyvinyl alcohol (PVA) fibers were gradually added and mixed until a consistent and homogenous mix was achieved. The mixes are then carefully poured into the specified molds. All specimens were cast in one concrete. The concrete was mixed in the concrete mixer, and the fibers were added to it. After mixing the specimen, the slump test was done. The concrete slump test measures the consistency of fresh concrete before it sets. It is performed to check the workability of freshly made concrete, and therefore the ease with which concrete flows. It can also be used as an indicator of an improperly mixed batch. The concrete was vibrated after being placed in the formwork. After one day the specimens were covered with burlap and sprinkled with water till the day of the tests. To compare the results before and after the retrofit with R-ECC, the test was redone. The replacement of rubber engineering cement composite was re-strengthened Reinforced Concrete beams.

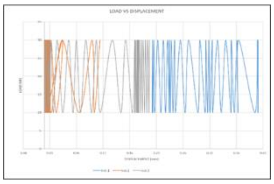
III. RESULTS & DISCUSSION

Three reinforced concrete beam units were prepared for static testing and harmonic fatigue loading in the laboratory. Each beam unit was tested according to a specific procedure until failure or cracking occurred. The results and discussion section provides a detailed justification for each finding to ensure its accuracy in relation to the study's initial objectives. This study evaluates the effect of R-ECC as a retrofitting material on the structural performance of reinforced concrete beams.

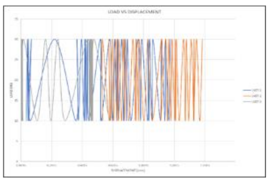
A. Load-Displacement

The load-displacement curves indicate a linear correlation between load and displacement across all specimens. Figure 6 presents the load-displacement graphs for Samples 2 and 3, both before and after retrofitting. Figures 6(a) and 6(b) illustrate the behavior before the application of R-ECC, whereas Figs. 6(c) and 6(d) depict the response after retrofitting with R-ECC. Overall, specimens reinforced with R-ECC exhibited greater displacement compared to those without R-ECC reinforcement. This study examined the structural behavior of reinforced concrete beams strengthened with R-ECC under shear and bending forces. The loading process continued until the specimens lost their capacity and reached the yield point. The observed failure modes included crushing, buckling, and rupture within the compression and tension zones [9].

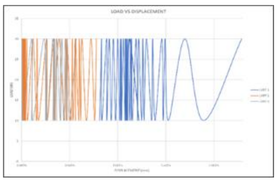
(a) Sample 2 Before Retrofitted



(b) Sample 3 Before Retrofitted



(c) Sample 2 and 3 Before Retrofitted

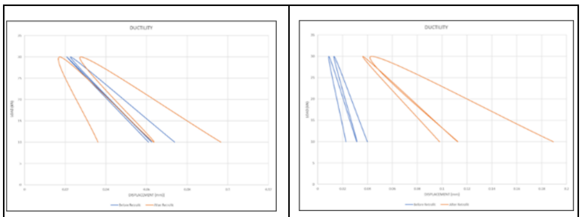


(d) Sample 2 and 3 After Retrofitted

Fig. 6. Load displacement graphs before and after retrofitted with R-ECC for sample 2 and 3.

B. Ductility

A study by Maghsoudi and Akbarzadeh Bengar [10] analyzed the ductility values of all specimens after being retrofitted with R-ECC. Figure 7 presents the ductility graphs for Samples 2 and 3, both before and after retrofitting. As shown in Fig. 7(a), the ductility values before the application of Rubberized Engineered Cementitious Composite (R-ECC) were lower, whereas Fig. 7(b) illustrates the increase in ductility after retrofitting with R-ECC. The incorporation of R-ECC enhanced the structure's ductility, enabling greater deformation before failure. This improvement is essential for energy dissipation during seismic events, increasing resilience and minimizing structural damage. However, before the application of R-ECC, ductility values were lower due to structural modifications that prioritized load-bearing capacity and stiffness. The ductility index, determined based on curvature at the first yield and ultimate points, reflects the energy absorption capability of the structural member. A higher ductility index indicates a more gradual failure process, allowing warning signs such as fine cracking to appear before total collapse.



(a) Sample 2 and 3 Before Retrofitted | (b) Sample 2 and 3 After Retrofitted

Fig. 7. Ductility graphs before and after retrofitted with R-ECC for sample 2 and 3.

IV. CONCLUSION & RECOMMENDATIONS

This study aimed to achieve two primary objectives. The first was to analyze the load-displacement behavior of RC beams retrofitted with R-ECC under fatigue loading. The second objective was to assess the structural performance of RC beams before and after retrofitting with R-ECC. Based on the findings, the load-displacement response and fatigue behavior of reinforced concrete beams incorporating mineral admixtures were evaluated.

- The load-displacement response of R-ECC demonstrated significant performance under fatigue loading conditions.
- Both experimental and analytical results exhibited a consistent trend in the load-displacement relationship.
- The retrofitted beam displayed improved energy dissipation and greater resistance to crack initiation and propagation compared to the non-retrofitted beam.
- The fatigue strength of the beam was determined by assessing the number of fatigue cycles it could withstand before failure due to fatigue loading.
- The strength and ductility of the RC beam increased after retrofitting with R-ECC, as the material possesses superior tensile strength and deformability, enhancing structural performance compared to conventional concrete.

For further research, increasing the crumb rubber content within a range of 10% to 20% is recommended to determine a more precise and optimal proportion. Additionally, investigating the bonding mechanism between R-ECC and concrete would provide valuable insights. Expanding the application of R-ECC to other structural elements, such as railway tracks or pavements, and experimenting with different crumb rubber sizes could further enhance its potential uses.

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PAPER CONTRIBUTION TO RELATED FIELD OF STUDY

The 9th SDG emphasis the need to building "a sustainable industry, innovation, and infrastructure to enable economic growth".

The creation and adoption of Sustainable Development Goal 11 (SDG 11), which aims to "Make cities and human settlements inclusive, safe, resilient, and sustainable" that they have no conflict of interest.

REFERENCES

[1] A. R. Sakulich and V. C. Li, "Nanoscale Characterization of Engineered Cementitious Composites (ECC)," *Cement and Concrete Res.*, vol. 41, no. 2, pp. 169–175, 2011.

[2] S. C. Paul and G. P. A. G. Van Zijl, "Crack formation and chloride induced corrosion in Reinforced Strain Hardening Cement-based Composite (R/SHCC)," *J. Adv. Concrete Technol.*, vol. 12, no. 9, pp. 340–351, 2014.

[3] W. S. Alaloul, M. A. Musarat, B. A Tayeh, S. Sivalingam, M. F. Bin Rosli, S. Haruna and M. I. Khan, "Mechanical and Deformation Properties of Rubberized Engineered Cementitious Composite (ECC)," *Case Stud. in Construct. Mater.*, vol. 13, pp. e00385, 2020.

[4] M. Murali, B. S. Mohammed, I. Abdulkadir, M. S. Liew and W. S. Alaloul, "Utilization of Crumb Rubber and High-Volume Fly Ash in Concrete for Environmental Sustainability: Rsm-based Modeling and Optimization," *Materials*, vol. 14, no. 12, pp. 3322, 2021.

[5] B. H. AbdelAleem ans A. A. A. Hassan, "Use of Rubberized Engineered Cementitious Composite in Strengthening Flexural Concrete Beams," *Eng. Struct.*, vol. 262, pp. 114304, 2022.

[6] H. H. M. Yusoff, K. A. Razak, F. Yuen, A. Harun, J. Talib, Z. Mohamad, Z. Ramli and R. A. Razab, "Mapping of Post-event Earthquake Induced Landslides in Sg. Mesilou using LiDAR," *IOP Conf. Series: Earth and Environ. Sci.*, vol. 37, pp. 012068, 2016.

[7] S. C. Chin, K. F. Tee, F. S. Tong, S. I. Doh and J. Gimbun, "External Strengthening of Reinforced Concrete Beam with Opening by Bamboo Fiber Reinforced Composites," *Mater. Struct.*, vol. 53, no. 6, pp. 141, 2020.

[8] A. A. Aziz, M. I. F. Rozli, K. D. A. Ghani, N. A. Jafri and N. Zakaria, "Effects of Pre-Treated Crumb Rubber as Sand Partial Replacement on Compressive Strength of Engineered Cementitious Composites (ECC)," *J. Mechanic. Eng., vol.* 20, no. 2, pp. 153–166, 2023.

[9] A. E. Uğur and A. Ünal, "Assessing the Structural Behavior of Reinforced Concrete Beams Produced with Macro Synthetic Fiber Reinforced Self-Compacting Concrete," *Structures*, vol. 38, pp. 1226–1243, 2022.

[10] A. A. Maghsoudi and H. A. Bengar, "Flexural Ductility of HSC Members," *Struct. Eng. and Mechanic*., vol. 24, no. 2, pp. 195–212, 2006.