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Manufacture and Characterization of Polymer Concrete Using Duck Egg Shell Powder, Areca Nut Fiber, and Epoxy Resin

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ABSTRACT

This research investigates the optimal composition of polymer concrete and its effects on physical and mechanical properties. Variations in composition were tested using a mixture of sand and eggshell powder in a 2:1 ratio, combined with areca nut fiber at concentrations of 0%, 4%, 8%, 12%, and 16%, and epoxy resin at levels of 20%, 25%, and 30%. Polymer concrete specimens were molded using a hot press at 90°C for 20 minutes. The study found that the optimal physical properties were achieved with a density of 1.61 g/cm³, porosity of 7.55%, and water absorption of 6.75%. The minimum physical properties recorded were a density of 1.11 g/cm³, porosity of 0.95%, and water absorption of 0.62%. The highest values observed for mechanical properties were a flexural strength of 54.13 MPa, compressive strength of 29.20 MPa, and tensile strength of 13.92 MPa. Conversely, the lowest mechanical properties were a flexural strength of 32.95 MPa, compressive strength of 8.65 MPa, and tensile strength of 2.94 MPa. SEM-EDX analysis revealed the presence of cavities within the samples and uneven distribution of epoxy resin, indicating areas where the resin clumped. The physical and mechanical properties of the polymer concrete in this study conform to the SNI 03-0691-1996 standards.

Keywords: Areca Nut Fiber, Eggshell Powder, Epoxy Resin, Polymer Concrete

ABSTRAK

Penelitian ini menyelidiki komposisi optimal dari beton polimer dan dampaknya terhadap sifat fisik dan mekanis. Variasi komposisi diuji menggunakan campuran pasir dan bubuk cangkang telur dengan rasio 2:1, dikombinasikan dengan serat pinang pada konsentrasi 0%, 4%, 8%, 12%, dan 16%, serta resin epoxy pada level 20%, 25%, dan 30%. Spesimen beton polimer dicetak menggunakan hot press pada suhu 90°C selama 20 menit. Studi ini menemukan bahwa sifat fisik optimal dicapai dengan kepadatan 1,61 g/cm³, porositas 7,55%, dan penyerapan air 6,75%. Sifat fisik minimum yang tercatat adalah kepadatan 1,11 g/cm³, porositas 0,95%, dan penyerapan air 0,62%. Nilai tertinggi yang diamati untuk sifat mekanis adalah kekuatan lentur 54,13 MPa, kekuatan tekan 29,20 MPa, dan kekuatan tarik 13,92 MPa. Sebaliknya, sifat mekanis terendah adalah kekuatan lentur 32,95 MPa, kekuatan tekan 8,65 MPa, dan kekuatan tarik 2,94 MPa. Analisis SEM-EDX mengungkapkan adanya rongga dalam sampel dan distribusi resin epoxy yang tidak merata, menunjukkan area di mana resin menggumpal. Sifat fisik dan mekanis beton polimer dalam penelitian ini sesuai dengan standar SNI 03-0691-1996.

Kata kunci: Beton Polimer, Bubuk Cangkang Telur, Resin Epoxy, Serat Pinang

1. Introduction

Concrete is one of the most widely used building materials in civil engineering due to its high compressive strength, durability, low maintenance requirements, and environmental accessibility. It does not need to be repainted or coated. Polymer concrete is a composite material where the binder consists of organic synthetic polymers or resins. It offers advantages such as resistance to water absorption, ultraviolet light, corrosion, and aggressive solvents like chemicals [1], [2].

Fibers are commonly added to improve the properties of brittle concrete, making it more ductile. The addition of fibers can enhance tensile strength and flexural strength. Increasing the aspect ratio of fibers affects concrete's tensile and flexural strength, and higher fiber content can improve these properties [3], [4]. Fibers contribute to the load-bearing capacity and flexibility of the concrete, preventing failure in their absence by transferring the load. Higher fiber content can also reduce segregation and to avoid cracking [5], [6].

Areca nut trees (*Areca catechu*) are native to Eastern Africa, Asia, and the Pacific, reaching heights of up to 25 meters [7], [8]. The trunks are commonly used for climbing, and while areca nut trees do not produce fruit for direct consumption, their fruits have historically been used in traditional medicine. Areca fibers comprise cellulose, hemicellulose, lignin, and ash [9], [10].

According to the North Sumatra Central Bureau of Statistics, approximately 13,448.98 tons of duck eggs were produced in the North Sumatra region in 2022. This production generates a significant amount of shell waste from human consumption and incubation waste in nurseries. The shell serves as a protective layer for the egg [11].

Research by Nurdin (2018) indicates that duck egg shells contain 97% calcium carbonate. This high calcium content makes duck egg shells a valuable material for cement production [12]. Epoxy resins, known for their superior mechanical properties and resistance to environmental aggressors compared to other resins, are often used despite their higher cost. Epoxy resins can also improve the curing process due to the heat they generate during curing [13].

This research aims to develop and characterize polymer concrete incorporating duck eggshell powder and areca nut fiber with epoxy resin. Specifically, this study seeks to optimize the mixture composition to enhance the physical and mechanical properties of the polymer concrete. By evaluating different proportions of areca nut fiber and epoxy resin, as well as the effects of duck eggshell powder, this research aims to create a composite material with improved performance for various construction applications.

2. Methods

2.1. Preparation of Duck Egg Shell Powder

Duck egg shells were cleaned, thoroughly washed, and dried in the sun. After drying, the shells were ground using a mortar and blended into a fine powder. The powder was then sieved through a 120-mesh sieve.

2.2. Preparation of Areca Nut Fibers

Select mature areca nuts and remove the skin. Clean the skin thoroughly and soak it in distilled water for 3 days. After soaking, clean the skin with running water and then comb it to produce fibers. Dry the fibers in the sun for approximately 3 days. Soak the dried fibers in 5% sodium hydroxide (NaOH) solution for 2 hours, then clean with running water to remove any remaining NaOH. Finally, dry the fibers in the sun and cut them to a length of approximately 3 cm.

2.3. Polymer Concrete Manufacturing Procedures

First, the raw materials were cleaned and sieved. The materials were then weighed according to the compositions specified in Tables 1, 2, and 3. The raw materials were mixed evenly using a mixer for 3 minutes. The mixed materials were placed into a mold coated with aluminum foil and wax. The mixture was pressed using a heat compressor at 90°C for 20 minutes.

Table 1. Composition of polymer concrete materials with 20% epoxy resin.

Samples' code	Sand (wt%)	Eggshell Powder (wt%)	Areca nut fiber (wt%)	Epoxy Resin (wt%)
A1	66.6	33.4	0	20
A2	64.6	31.4	4	20
A3	62.6	29.4	8	20
A4	60.6	27.4	12	20
A5	58.6	25.4	16	20

Table 2. Composition of polymer concrete materials with 25% epoxy resin.

Samples' code	Sand (wt%)	Eggshell Powder (wt%)	Areca nut fiber (wt%)	Epoxy Resin (wt%)
B1	66.6	33.4	0	25
B2	64.6	31.4	4	25
B3	62.6	29.4	8	25
B4	60.6	27.4	12	25
B5	58.6	25.4	16	25

Table 3. Composition of polymer concrete materials with 30% epoxy resin.

Samples' code	Sand (wt%)	Eggshell Powder (wt%)	Areca nut fiber (wt%)	Epoxy Resin (wt%)
C1	66.6	33.4	0	30
C2	64.6	31.4	4	30
C3	62.6	29.4	8	30
C4	60.6	27.4	12	30
C5	58.6	25.4	16	30

3. Results and Discussion

3.1. Density Test

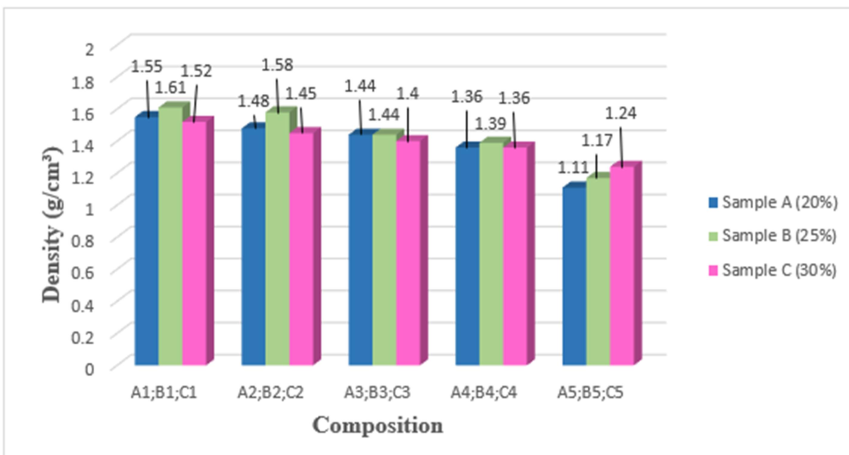

Figure 1. Graph of density relationship vs. concrete composition.

The highest density observed was 1.61 g/cm³ in sample B1, with a composition of (66.6:33.4:0) at 25% epoxy resin variation. The lowest density of 1.11 g/cm³ was obtained in sample A5, with a composition of (58.6:25.4:16) at 20% epoxy resin variation. Reducing the composition of sand and eggshells results in a lower density value while adding more areca nut fiber also decreases density. The density value increases with an increase in resin addition from 20% to 25% but falls when the resin addition rises from 25% to 30%.

3.2. Porosity Test

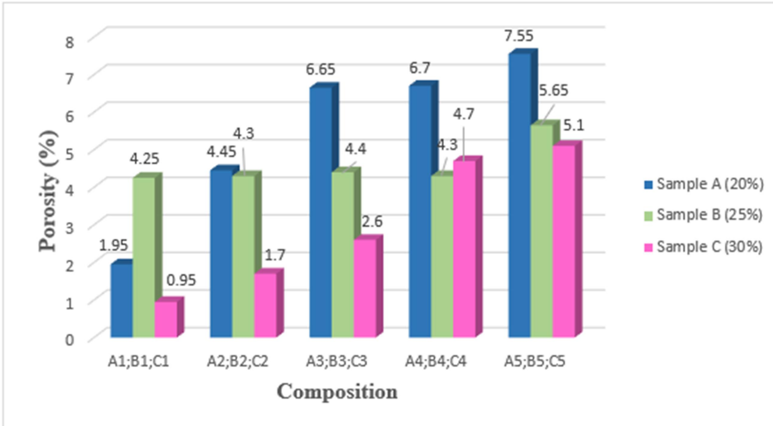

Figure 2. Graph of porosity relationship vs. concrete composition.

The highest porosity value of 7.55% was found in sample A5, with a composition of (58.6:25.4:16) and 20% epoxy resin. The lowest porosity of 0.95% was observed in sample C1, with a composition of (66.6:33.4:0) and 30% epoxy resin. Decreasing the sand and eggshell powder composition increases the porosity while increasing the areca nut fiber content also raises the porosity. This indicates that adding more areca nut fibers produces a polymer concrete with larger voids. On the other hand, including 20%, 25%, and 30% epoxy resin variants reduce the porosity. Adding epoxy resin fills the voids in the polymer concrete, reducing the porosity.

3.3. Water Absorption Test

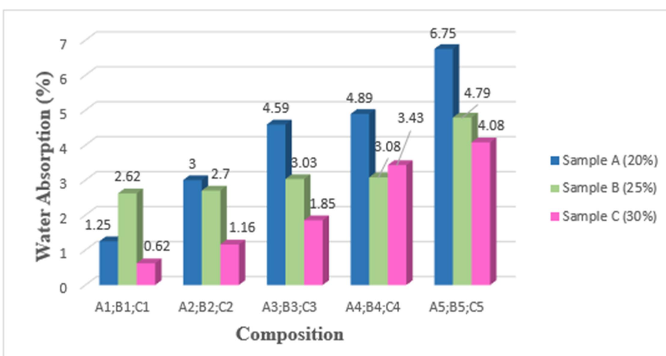

Figure 3. Graph of water absorption relationship vs. concrete composition.

The maximum water absorption value of 6.75% was recorded for sample A5, with a composition of (58.6:25.4:16) and 20% epoxy resin. The lowest water absorption value was 0.62% in sample C1, with a composition of (66.6:33.4:0) and 30% epoxy resin. Water absorption increases with a decrease in sand and eggshell powder content and an increase in Areca nut fiber content in polymer concrete. This is due to the formation of voids from adding more areca nut fibers, which can lead to higher water absorption.

3.4. Flexural Strength Testing

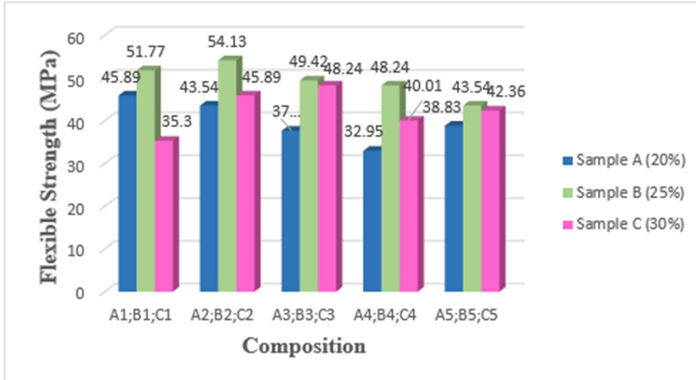

Figure 4. Graph of flexural strength relationship vs. concrete composition.

The highest flexural strength of 54.13 MPa was observed in sample B2, with a composition of (64.6:31.4:4) and 25% resin variation. The lowest flexural strength of 32.95 MPa was recorded in sample A4, with 20% resin variation. The graph shows that decreasing the sand and eggshell powder mixture results in a drop in flexural strength in samples A and B. However, in sample C, the flexural strength increases. The inclusion of Areca nut fiber can lead to a reduction in flexural strength in compositions A and B but an increase in composition C. Increasing the epoxy resin content to 25% enhances the flexural strength, whereas 30% resin reduces it.

3.5. Compressive Strength Testing

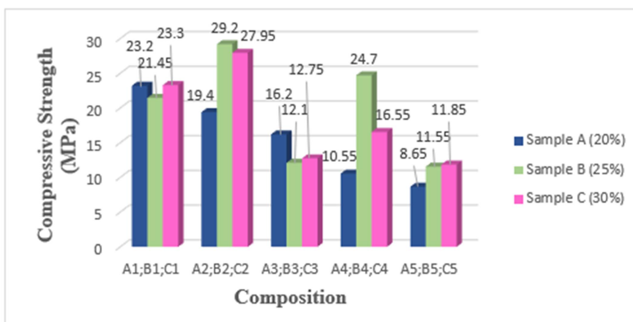

Figure 5. Graph of compressive strength relationship vs. concrete composition.

The highest compressive strength of 29.20 MPa was found in sample B2, with a composition of (64.6:31.4:4) and 25% epoxy resin. The lowest compressive strength of 8.65 MPa was observed in sample A5, with a composition of (66.6:33.4:0) and 20% epoxy resin. Reducing the sand and eggshell powder composition decreases compressive strength, but increasing it in samples B and C and Areca nut fiber shows varying results. Compressive strength decreases with 20% to 25% resin variation but increases in samples B2, B4, and B5. This improvement is due to the homogeneity of the mixture. The compressive strength improves with 25% to 30% resin addition, although samples C2 and C4 show a decline.

3.6. Tensile Strength Testing

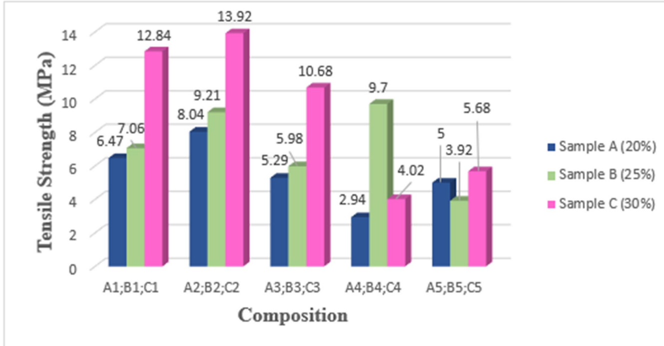

Figure 6. Graph of tensile strength relationship vs. concrete composition.

The highest tensile strength of 13.92 MPa was observed in sample C2, with a composition of (64.6:31.4:4) and 30% epoxy resin. The lowest tensile strength of 2.94 MPa was recorded in sample A4, with a composition of (60.6:27.4:12) and 20% epoxy resin. Tensile strength increases and decreases with changes in sand and eggshell powder proportions in samples A, B, and C. The addition of Areca nut fiber generally boosts tensile strength, while excessive fiber reduces it. The epoxy resin functions as a binder, increasing tensile strength with varying resin content.

3.7. Microstructural Testing of sample A2

SEM analysis of polymer concrete sample A2, using sand, eggshell powder, areca nut fiber, and epoxy resin adhesive at 90°C for 20 minutes, is shown in the figure 7. SEM imaging of sample A2 with a composition of (64.6:31.4:4) and 20% epoxy resin at 100x magnification reveals significant voids due to the non-homogeneous mixture of materials. The grayish-white color indicates an uneven distribution of epoxy resin.

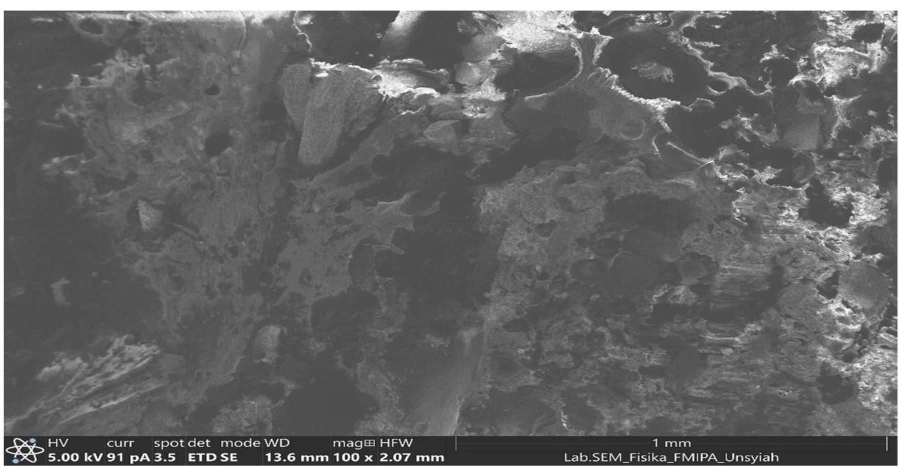

Figure 7. SEM results of sample A2 with 100x magnification.

The SEM analysis of Sample A2, a polymer concrete composed of (64.6% sand, 31.4% eggshell powder, 4% areca nut fiber) and 20% epoxy resin, was conducted at 100x magnification with a 1 mm diameter field of view. The image reveals that the thick black areas indicate numerous voids in the polymer concrete. These voids are a result of the mixture of materials that are not homogeneous. In contrast, the grayish-white areas show the uneven distribution of the epoxy resin.

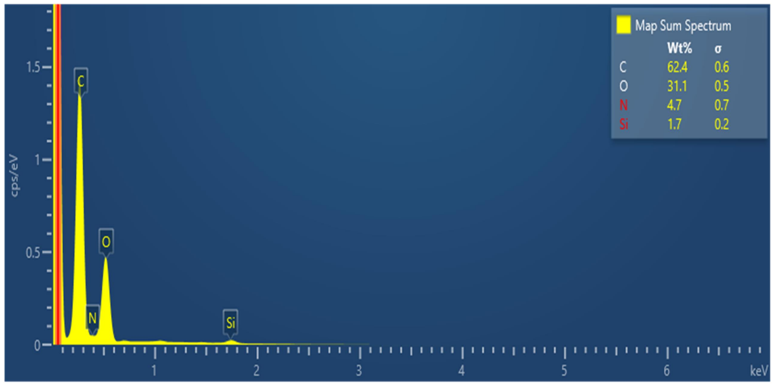

Figure 8. EDX results on sample A2.

The EDX results show that the predominant element in A2 polymer concrete is Element C, with other elements including Oxygen (O), Nitrogen (N), and Silicon (Si).

3.8. Microstructural Testing of Sample B2

SEM analysis of polymer concrete sample B2, using sand, eggshell powder, areca nut fiber, and epoxy resin adhesive at 90°C for 20 minutes, is presented in the figures. SEM imaging of sample B2 with a composition of (64.6:31.4:4) and 25% epoxy resin at 100x magnification shows that the increased volume of epoxy resin from 20% to 25% results in more voids due to the resin's inadequate binding ability.

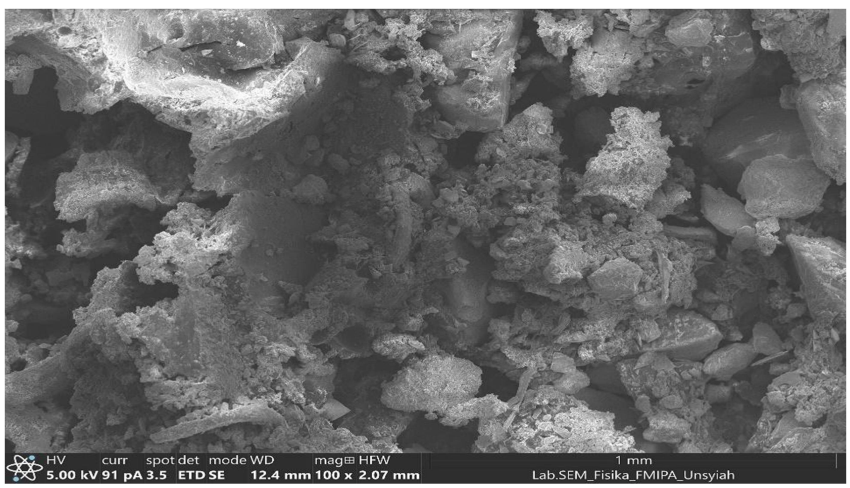

Figure 9. SEM results on sample B2 with 100x magnification.

The SEM analysis of Sample B2, a polymer concrete with a composition of (64.6% sand, 31.4% eggshell powder, 4% areca nut fiber) and 25% epoxy resin, was conducted at 100x magnification with a 1 mm diameter field of view. The image shows an increased number of voids in the polymer concrete. This increase in voids is attributed to the higher epoxy resin content (25% compared to 20%) and the resin's reduced ability to bind the materials effectively.

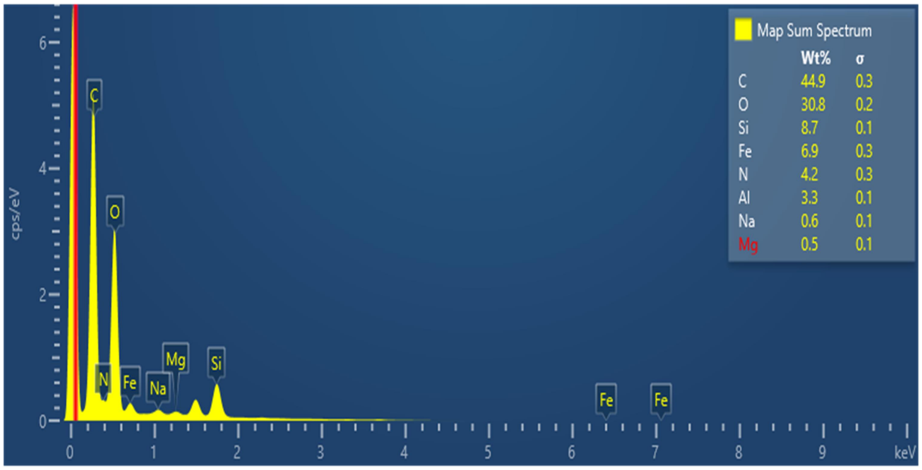

Figure 10. EDX results on sample B2.

The EDX results indicate that Element C is the most dominant element in B2 polymer concrete. Silicon (Si) content increased, while Oxygen (O) content decreased compared to sample A2. Additional elements detected include Iron (Fe), Nitrogen (N), Aluminum (Al), Sodium (Na), and Magnesium (Mg).

3.9. Microstructural Testing of Sample C2

SEM analysis of polymer concrete sample C2, with a composition of (64.6:31.4:4) and 30% epoxy resin, is shown in the figures. SEM imaging at 100x magnification reveals an even composition distribution, with minimal uneven points. The grayish-white color indicates the uniform appearance of the epoxy resin enveloping the mixture.

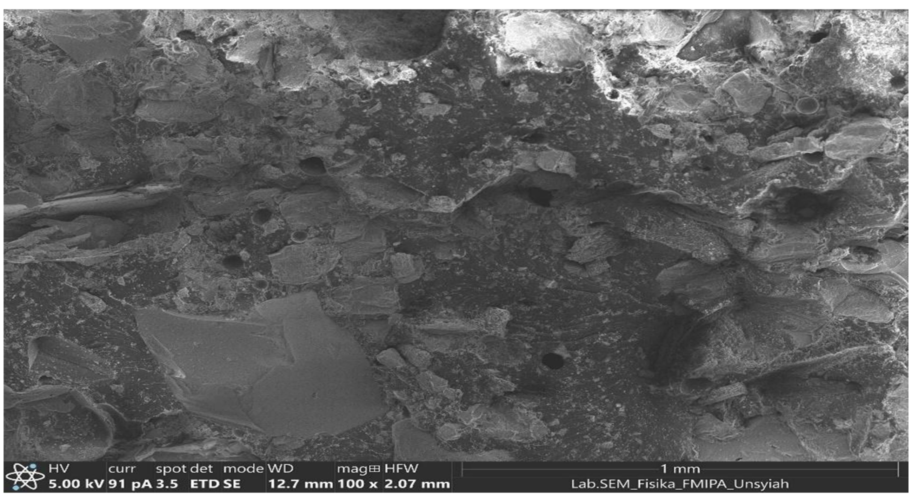

Figure 11. SEM results of sample C2 with 100x magnification.

The SEM analysis of Sample C2, a polymer concrete with a composition of (64.6% sand, 31.4% eggshell powder, 4% areca nut fiber) and 30% epoxy resin, was conducted at 100x magnification with a 1 mm diameter field of view. With the addition of 30% epoxy resin, the distribution of the components is notably even, with only a few isolated non-uniform areas. The grayish-white color in the image indicates that the epoxy resin effectively envelops the mixture of materials, providing a more uniform appearance.

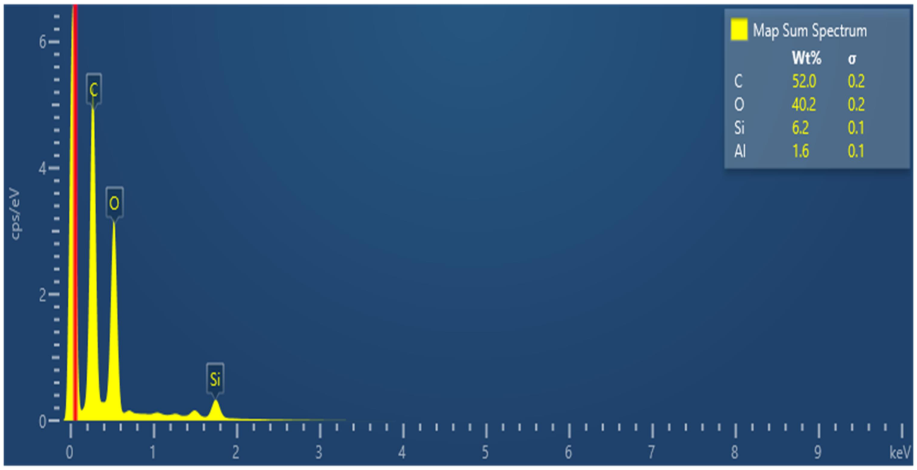

Figure 12. EDX results on sample C2.

EDX results show that the dominant element in C2 polymer concrete is Element C. Additional detected elements include Silicon (Si) and Aluminum (Al).

4. Conclusion

In conclusion, areca nut fiber can be used as a filler to enhance the flexural and tensile strengths in the manufacture of polymer concrete. However, excessive fiber addition reduces these strengths and is influenced by the mixture of other materials. The polymer concrete characteristics produced in this study meet the SNI 03-0691-1996 standards, with density values of 1.11-1.61 g/cm³, porosity values of 0.95-10.65%, water absorption values of 0.62-9.02%, flexural strength values of 32.95-54.13 MPa, compressive strength values of 8.65-29.20 MPa, and tensile strength values of 2.94-13.92 MPa. This study qualifies the concrete as quality D with a minimum compressive strength of 8.5 MPa and a maximum water absorption of 10%. It can be used as a substitute for conventional quality D concrete in construction. The optimal composition for fabricating and characterizing polymer concrete with eggshell powder aggregate and areca nut fiber as filler was found to be A2 (64.6:31.4:4) at 20% resin, B2 (64.6:31.4:4) at 25% resin, and C2 (64.4:31.4:4) at 30% resin. In these compositions, the test results of physical and mechanical properties meet the SNI 03-0691-1996 standard. The optimal composition for fabricating and characterizing polymer concrete with eggshell powder and areca nut fiber as filler was found in sample B2 (64.6:31.4:4) with 25% epoxy resin. At 25% resin, the material blend performs better than with 20% or 30% resin. In this composition, the test results of physical and mechanical properties comply with SNI 03-0691-1996.

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