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# Manufacture and Characterization of Polymer Concrete with Pumice Aggregates, Banana Stem Fibers, and Styrofoam Waste as Fillers

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**Abstract.** This study aims to determine the effect of replacing some fractions of pumice stone with banana stem fiber in polymer concrete. The ratio of sand, pumice stone, and banana stem fiber were (25:35:0), (25:33:2), (25:31:4), (25:29:6), (25:27:8) in units of weight %. The matrix used was 10% of styrofoam with the addition of 40% epoxy resin. Parameters tested include physical tests (density, porosity, and water absorption), mechanical tests (hardness, flexural strength, and compressive strength), microstructure, and elemental content tests using SEM-EDX. The test results show that the optimum physical properties for density are 1.4 g/cm$^3$, porosity 0.25 %, and water absorption 0.204 %. Meanwhile, the optimum value of mechanical properties in the hardness test is 56.0166 HVN, the flexural strength 26.830 MPa, and the compressive strength 34.082 MPa. Moreover, the morphological and elemental analysis results showed the formed pores, the distribution of the epoxy, and the elements loaded on the polymer concrete samples.

**Keywords:** Banana stem fiber, Polymer concrete, SEM-EDX, Styrofoam.

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## 1 Introduction

Technology development in Indonesia continues to be improved to accelerate the growth and development of industry in Indonesia. This increase in business and industry is in line with the increasing number of infrastructures which is a major factor in the acceleration of the industry [1]. This has increased the cost of building and maintaining industrial infrastructure, and the component that consumes many budgets is development, namely concrete as the foundation and core of infrastructure development. To get around the maintenance and development figures, polymer-based concrete models were developed that are easier and cheaper in manufacturing and maintenance with strengths that are no less good than conventional concrete use.

In general, concrete is a structural material produced using water; portland concrete is fine and rough, resulting in something hard [2]. Expanding polymers into concrete mixtures can improve

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the quality of concrete such as increasing strength, lowering concrete mass, and resistance to corrosive processes and being able to reduce production costs. Polymerized concrete is concrete with the addition of polymers as additional cement for powerful combinations, resulting in cement that works faster with superior compressive strength values. Additional materials can be plastic emulsions as well as other materials. This type is suitable for use in substantial crisis work that requires great power in a short time, even within a few hours [3]. Although this polymer concrete itself, in terms of quality, is not much different from conventional concrete, in terms of concrete treatment, it is somewhat easier and more economical than conventional concrete.

This polymer concrete binder itself is a polymeric material; the polymer material that is commonly used is in the form of resin. The resin itself has many types, one of which is epoxy resin. These epoxy resins form a cross matrix of high strength and high affinity to various substrates. Epoxy generally has excellent properties. In other words, it has an excellent ability to bind metal alloys and is tough. Epoxy resins are widely used in composites on various structural components. This leads to epoxy's ideal use in concrete applications that require high strength. Some remarkable properties of epoxy are low shrinkage during discharge, brilliant compound clogging, the ability to stick to impenetrable substrates, and exceptional adaptability [4,5]. In addition to the binding material, concrete requires several other components, namely aggregates and other stuffing materials, to improve its mechanical and physical properties.

The aggregate referred to here is an ordinary mineral molecule that functions as a filler in a large mixture. Despite its name as a filler material, this aggregate amount occupies up to 70% of the volume of concrete. The selection of aggregates is very important because it greatly affects the properties of concrete [6]. The commonly used aggregates to reduce concrete mass are pumice and volcanic rocks, commonly distributed in various parts of the world. The use of pumice itself is better known as a natural lightweight aggregate that is strong enough and light enough to be used in making concrete.

Nevertheless, adding a percentage of pumice to concrete will reduce the density value of the concrete. This certainly affects the compressive strength value. Therefore, increasing the percentage of pumice in a concrete composition will reduce its compressive strength [7].

To repair and fill the voids that are still produced in concrete, it is necessary to add fillers, which can be in the form of fibers or other substances. In this case, the research developed uses fillers in the form of banana stem fibers and polymeric materials in the form of styrofoam. Styrofoam is a thermoplastic polymer that contains more than 98% polystyrene and is widely used as a food wrapper [8]. However, styrofoam is difficult to decompose naturally, so it is necessary to find ways to utilize styrofoam for other useful materials such as composites, membranes, and others [9]. Furthermore, using used styrofoam as a composite produces composites with low mechanical strength and requires the addition of reinforcement [10]. Today composite materials made of natural fibers are widely used for their advantages compared to synthetic fibers: low specific gravity, abrasion resistance, good electrical resistance, and excellent soundproofing [11]. Natural fibers used as composite reinforcement include bamboo, wood, coconut, cotton, flax, banana, and pineapple [12]. By combining these two filling elements, it is hoped that it will produce better and higher quality concrete.

## 2 Methods

### 2.1 Banana Stem Fiber Preparation

Banana stems were cleaned and cut 12 cm long, then shriveled to facilitate obtaining fiber. The banana stem that had been shriveled was then soaked in a water container for approximately one week until the fibers are properly obtained. The fiber that had been obtained was then rinsed thoroughly using water 3-4 times so that the rest of the banana stem that was not needed was separated from the fiber. Then the fiber was squeezed and dried in the sun until completely dry for about 1-2 days. Furthermore, these dried fibers were cut into small pieces sized 1-3 cm.

### 2.2 Preparation of Styrofoam Solution

Styrofoam waste from electronic equipment protectors was cleaned and cut into small pieces of about 1 cm. Then it was weighed and mixed with toluene using a ratio of styrofoam mass and toluene mass of 1: 2, followed by stirring for a while using a spatula, then heated and stirred using a magnetic stirrer at a temperature of 80°C for 15 minutes to produce a homogeneous solution. After finishing the styrofoam solution, it was then stored in a container in the form of a vial bottle.

### 2.3 Concrete Making Process

The materials used were sand, pumice, styrofoam solution, banana stem fiber, and epoxy resin. First, they were weighed according to the predetermined composition, namely 25% sand, 35% pumice stone, 0% banana stem fiber, styrofoam solution with variations (0 and 10) % and 40% epoxy resin. Second, the weighed dry matter was poured into the beaker glass, and styrofoam solution and epoxy were added. Then, the ingredients were mixed using a spatula until it was completely flat and the dry matter did not coagulate.

Next, the sample mold and iron plate were prepared; the sample mold was coated with wax, while the iron plate was coated using aluminum foil. The mold was then placed on one of the iron plates. Next, the concrete dough was poured into the mold until it was filled and evenly distributed. After pouring the dough, the iron mold was closed using an iron plate coated with styrofoam. Next, the mold was placed in the hot compressor machine previously heated and set the temperature to 90°C; the mold was pressed in the hot compressor machine for 20 minutes. After 20 minutes, the mold was removed from the hot compressor machine, and the concrete sample was taken from the mold.

### 2.4 Characterization

The characterization of polymer concrete consists of physical properties (density and absorption of water), mechanical properties (hardness, bending strength, and compressive strength), and microstructure (SEM-EDX).

## 3 Result and Discussion

### 3.1 Physical Properties Analysis

*A. Density Test*

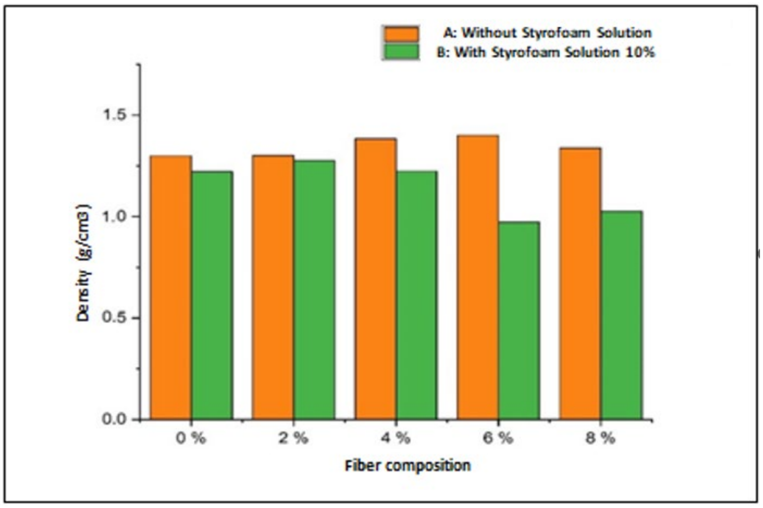



**Figure 1.** The relationship between density and composition

Figure 1 shows that as the fiber increases, the density value obtained tends to decrease. This is because when mixed with other materials, the fibers cause empty gaps that give rise to voids. The correlation that can be concluded is that the lower the density value, the more the pores on the surface will increase.

The results of observations show that the best condition is in the composition with the addition of fiber as much as 2% by 1.301 g/cm$^3$. This shows that the resulting polymer concrete generally has a good surface density and is still classified as lightweight concrete with light structural uses because the density value ranges from (0.800 - 1.400) g/cm$^3$.

*B. Water Absorption Test*

From Figure 2, the minimum water absorption value for variation A is estimated at 0.230%, while for variation B, it is at 0.204%. The water absorption value in polymer concrete is relatively small, ranging (from 0.230 - 1.008) % for variation A (without Styrofoam solution) and range (0.204 - 6.042)% for variation B (with styrofoam solution). This is due to the nature of epoxy resin which acts as a binder that can unite the structure of the aggregate and filler material of polymer concrete to minimize the formation of cavities in the sample, and the value of water absorption obtained is relatively low. Based on SNI 03-0349-1989, concrete's average water absorption value ranges from 25-35%. Therefore, referring to the SNI, the polymer concrete produced in this study has met the requirements set for concrete.

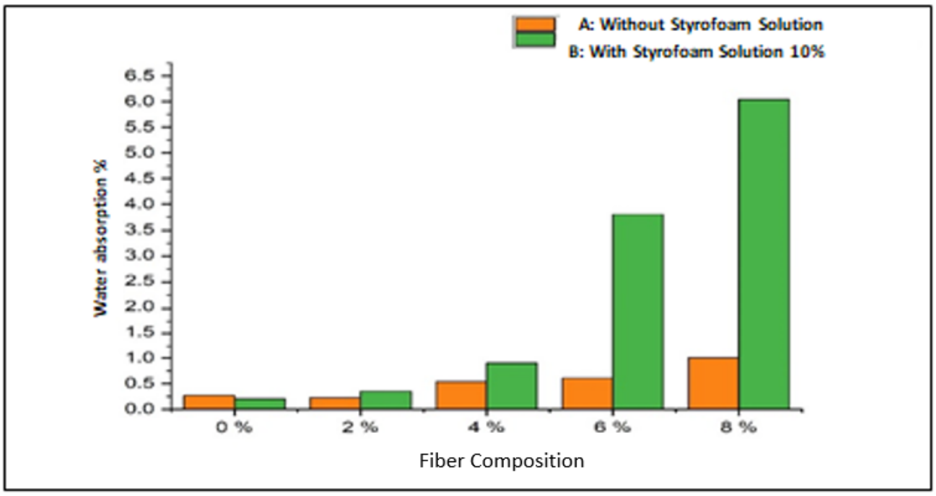



**Figure 2.** The relation between water absorption and composition

## 3.2 Mechanical Properties Analysis

### *A. Hardness Test*

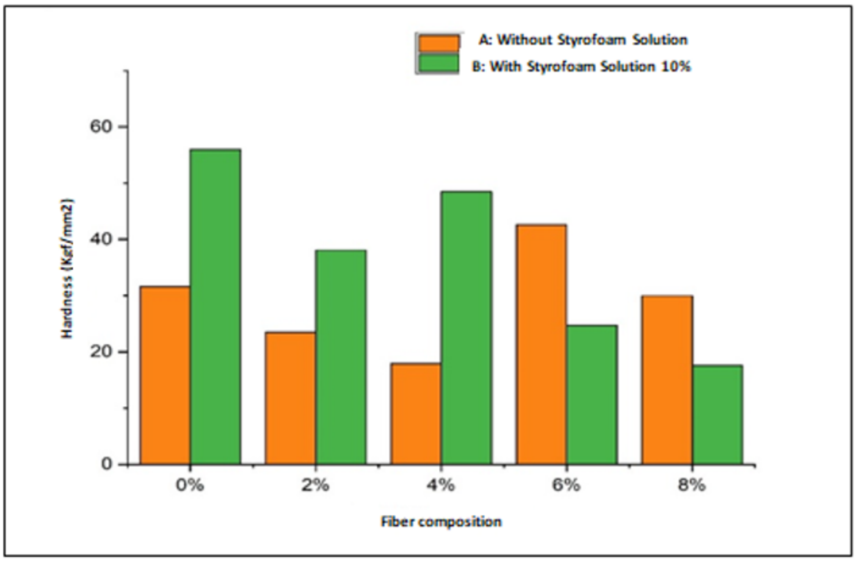



**Figure 3.** The relation between violence and composition

From Figure 3, the hardness value of polymer concrete tends to decrease. However, there is a spike in the hardness value that is quite high in the fiber mass composition of 6% for variation A and the fiber mass composition of 4% for variation B. The hardness value increases due to the sample density value have increased.

From the data above, the optimum hardness value of polymer concrete is also obtained in the fiber mass composition of 0% for variation B of 56.016 HVN. In comparison, variation A is found in the composition of fiber mass of 6% of 42.6111 HVN. Based on a previous study, the optimum hardness value was 117 HVN [13]. Meanwhile, this study produced an optimum hardness value of 56.016 HVN.

*B. Bending Strength Test*

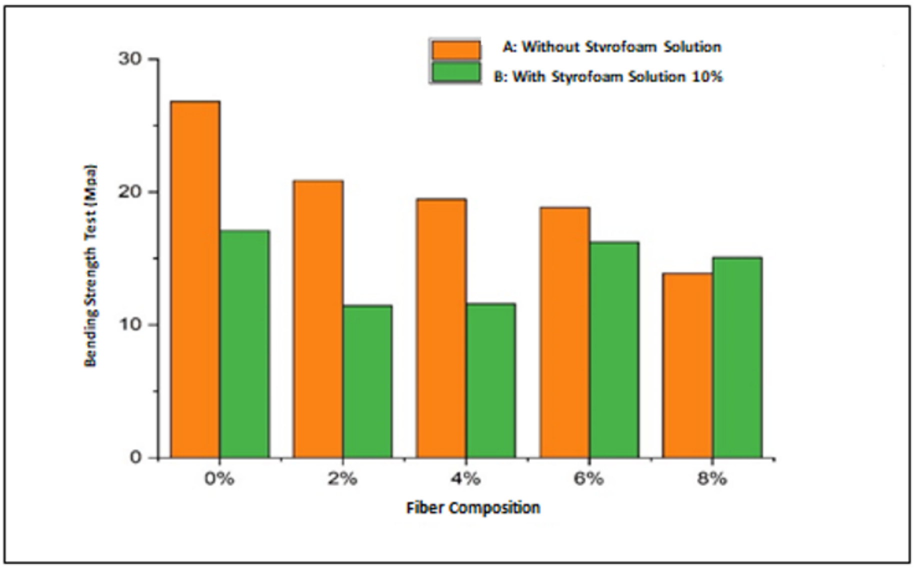



**Figure 4.** The relation between strong bending and composition

Figure 4 shows the optimum polymer concrete bending strength produced in this study of 26.803 MPa for variation A and 17.009 MPa for variation B. In comparison, the research [13] found that the bending strength value was 22.08 MPa, and it can be concluded that the bending strength value in this study is better than the previous study.

*C. Compressive Strength Test*

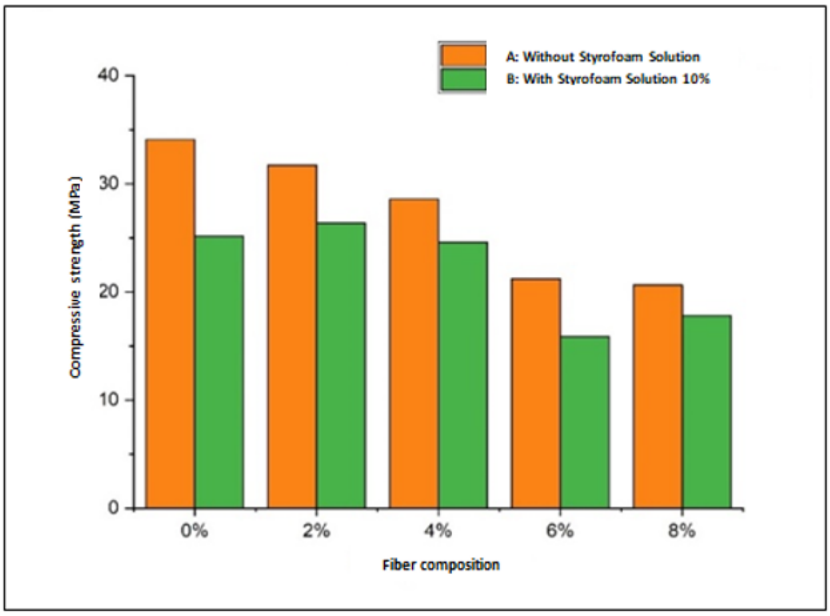
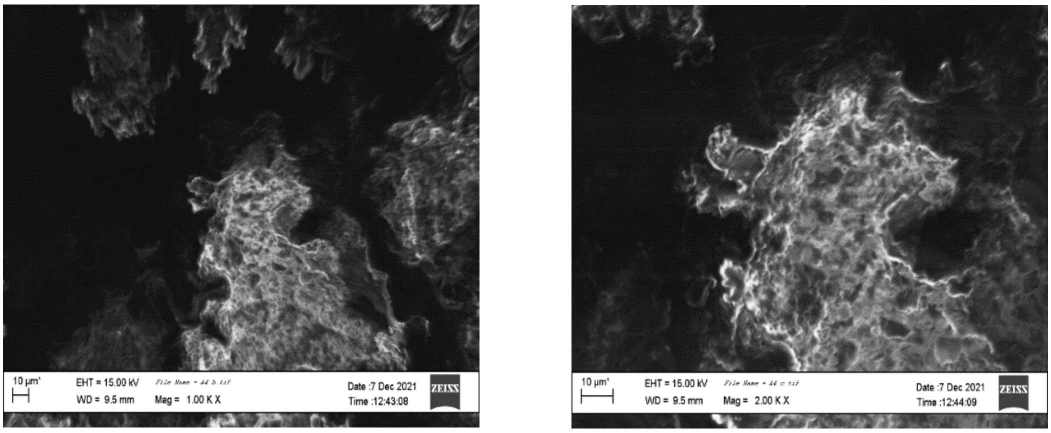



**Figure 5.** The relation between compressive strength and composition

Based on Figure 5, it can be concluded that adding banana stem fibers and the reduction of pumice which affect the compressive strength value of polymer concrete. In the previous study, polymer concrete's optimum compressive strength value was 23.63 MPa, and the minimum compressive strength value was 4.49 MPa [14]. Meanwhile, this study produced an optimum compressive strength value of 34.082 MPa, and the minimum compressive strength value was 15.866 MPa. So, it can be said that this research can increase the strength of polymer concrete with constituent materials in the form of pumice, sand, and banana stem fibers, as well as styrofoam solutions and epoxy resins which act as binders between materials.

### 3.3 SEM-EDX Characterization

*A. SEM-EDX Characterization Results sample A2*




(a) (b)

**Figure 6.** Concrete Sample Morphology A2 (a) Magnification 1000 times (b) Magnification 2000 times

Based on the results of morphological observations of A2 concrete samples using SEM with a magnification of 1000 times and 2000 times a diameter of 10 µm (Figure 6), several things can be concluded; namely, the formation of pore pores and the distribution of epoxy resin in the A2 sample can be seen. The deep black color in the picture shows the pores formed, while the grayish-white color is the distribution of epoxy adhesive materials. Based on morphological images, samples of this mixture of raw materials have not been distributed optimally in the process of making polymer concrete with a composition (25:29:6:0:40) in percent by weight for sand, pumice, banana stem fibers, styrofoam solution, and epoxy resin because the pores produced tend to be large and quite a lot.

Based on Figure 7 and Table 1, the dominant material element of the sample above is the silica (Si) element of 16.27%, which indicates that the nature of pumice is dominant to concrete samples; this is one of the supporting factors that affect the strength of concrete. However, there is still an air cavity indicated by the percentage of oxygen (O) elements of 55.25%; this indicates that the mixing of concrete raw materials is still not mixed evenly, so an air cavity is formed. In addition, it can be seen from the elemental analysis data showing several other elements such as iron (Fe), aluminum (Al), sodium (Na), potassium (K), magnesium (Mg), calcium (Ca), and chlorine (Cl).

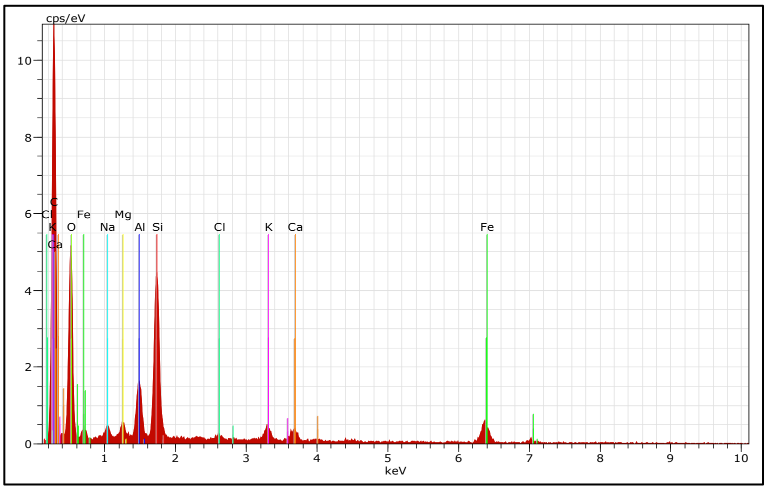


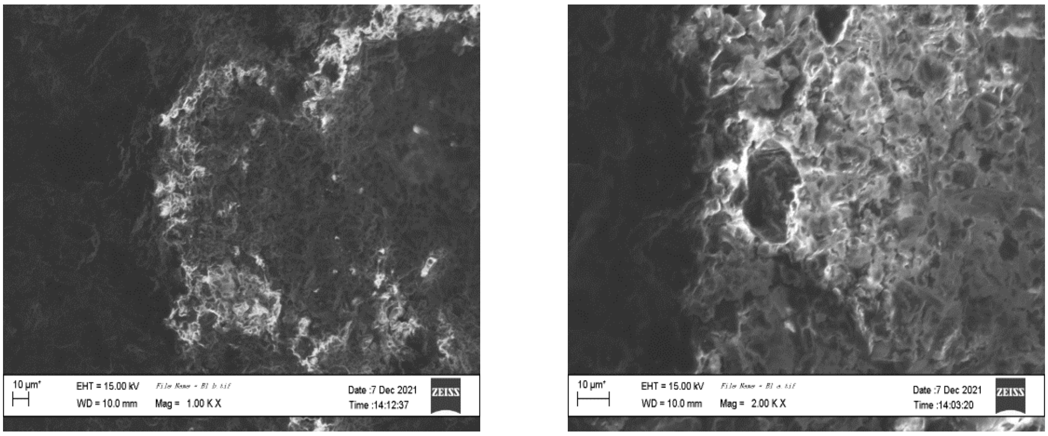

**Figure 7.** Graph of EDX Results of A2 Concrete Samples

**Table 1.** Data of EDX Results of A2 Concrete Samples

Spectrum: A2

| El | AN | Series | unn. C [wt.%] | norm. C [wt.%] | Atom. C [at.%] | Error (1 Sigma) [wt.%] | K fact. | Z corr. | A corr. | F corr. |
|---|---|---|---|---|---|---|---|---|---|---|
| O | 8 | K-series | 33.10 | 55.25 | 71.20 | 5.02 | 0.607 | 0.911 | 1.000 | 1.000 |
| Si | 14 | K-series | 9.75 | 16.27 | 11.94 | 0.47 | 0.061 | 2.667 | 1.000 | 1.004 |
| Fe | 26 | K-series | 6.46 | 10.79 | 3.98 | 0.28 | 0.034 | 2.986 | 1.000 | 1.052 |
| Al | 13 | K-series | 4.27 | 7.13 | 5.45 | 0.26 | 0.036 | 1.984 | 1.000 | 1.009 |
| Na | 11 | K-series | 1.80 | 3.01 | 2.70 | 0.19 | 0.019 | 1.543 | 1.000 | 1.004 |
| K | 19 | K-series | 1.40 | 2.34 | 1.24 | 0.10 | 0.007 | 3.069 | 1.000 | 1.023 |
| Mg | 12 | K-series | 1.38 | 2.30 | 1.95 | 0.13 | 0.013 | 1.813 | 1.000 | 1.008 |
| Ca | 20 | K-series | 1.36 | 2.27 | 1.17 | 0.10 | 0.008 | 2.937 | 1.000 | 1.025 |
| Cl | 17 | K-series | 0.38 | 0.64 | 0.37 | 0.06 | 0.002 | 2.757 | 1.000 | 1.013 |
| | | Total: | 59.92 | 100.00 | 100.00 | | | | | |

## *B. SEM-EDX Characterization Results of Sample B2*




(a) (b)

**Figure 8.** Concrete Sample Morphology B2 (a) Magnification 1000 times (b) Magnification 2000 times

Based on the results of morphological observations of B2 concrete samples using SEM with a magnification of 1000 times and 2000 times with a diameter of 10 μm (Figure 8), several things can be concluded; namely, the formation of pore pores and the distribution of epoxy resin in B2 samples can be seen. The deep black color in the picture shows the pores formed, while the grayish-white color is the distribution of epoxy adhesive materials. Therefore, this mixture of raw materials is already distributed quite maximally in making polymer concrete with a composition (25:25:0:10:40) in percent by weight for sand, pumice, banana stem fibers, styrofoam solution, and epoxy resin due to much fewer pores and air cavities.

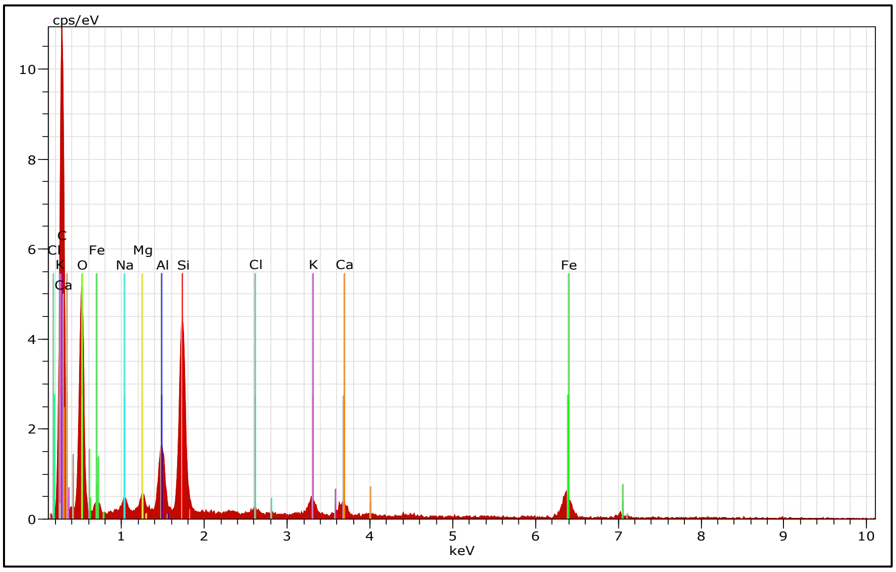



**Figure 9.** Graph of EDX Results of B2 Concrete Samples

**Table 2.** Data of EDX Results of B2 Concrete Samples

Spectrum: B2

| El | AN | Series | unn. C [wt.%] | norm. C [wt.%] | Atom. C [at.%] | Error (1 Sigma) [wt.%] | K fact. | Z corr. | A corr. | F corr. |
|---|---|---|---|---|---|---|---|---|---|---|
| O | 8 | K-series | 31.97 | 49.06 | 63.86 | 5.10 | 0.582 | 0.843 | 1.000 | 1.000 |
| Si | 14 | K-series | 16.89 | 25.92 | 19.22 | 0.78 | 0.111 | 2.325 | 1.000 | 1.003 |
| Al | 13 | K-series | 6.30 | 9.67 | 7.46 | 0.36 | 0.055 | 1.729 | 1.000 | 1.014 |
| Fe | 26 | K-series | 2.63 | 4.03 | 1.50 | 0.17 | 0.015 | 2.617 | 1.000 | 1.061 |
| Na | 11 | K-series | 2.14 | 3.28 | 2.97 | 0.21 | 0.024 | 1.343 | 1.000 | 1.006 |
| Ca | 20 | K-series | 1.76 | 2.70 | 1.40 | 0.11 | 0.010 | 2.567 | 1.000 | 1.018 |
| K | 19 | K-series | 1.61 | 2.47 | 1.31 | 0.11 | 0.009 | 2.682 | 1.000 | 1.018 |
| Mg | 12 | K-series | 1.37 | 2.10 | 1.80 | 0.13 | 0.013 | 1.579 | 1.000 | 1.011 |
| Cl | 17 | K-series | 0.51 | 0.78 | 0.46 | 0.06 | 0.003 | 2.407 | 1.000 | 1.011 |
| | | Total: | 65.17 | 100.00 | 100.00 | | | | | |

From Figure 9 and Table 2, the more dominant material element is silica (Si) by 25.92% for B2 concrete samples. Compared to the composition of A2 silica concrete obtained for B2 concrete, it increased by 9.65%. A decrease followed the increase in silica elements in the percentage of oxygen elements, which was reduced by 6.19% from the data obtained by A2 concrete samples. In addition, it can be seen from the elemental analysis data showing that several other elements such as iron (Fe), aluminum (Al), sodium (Na), potassium (K), magnesium (Mg), calcium (Ca), and chlorine (Cl) also experience fluctuating value changes. This condition affects the morphology of the resulting concrete, as evidenced by Figures 6 and 8, which show that the pores/air cavities produced by concrete composition B2 are less than those of concrete composition A2.

## 4 Conclusion

The addition of styrofoam solution to the composition of polymer concrete broadly increases the physical strength of the polymer concrete produced because, in this study, the styrofoam solution acts as a filler that functions to fill the voids between materials. The addition of a 10% styrofoam solution obtained an optimum density value of 1.271 g/cm$^3$, an optimum porosity value of 0.25%, and an optimum water absorption value of 0.204%. The optimal composition in the manufacture and characterization of polymer concrete with pumice aggregates and banana stem fibers, and styrofoam waste as fillers are found in the compositions of A2 (25:33:2:0:40) and B2 (25:23:2:10:40) for sand, pumice, banana stem fibers, styrofoam solution and epoxy resin expressed in units of percent by weight. In this composition, the results of testing physical and mechanical properties have values that have met the SNI standard 03-0691-1996. Furthermore, the characteristics of polymer concrete obtained in this study have met SNI 03-0691-1996, where the average value of water absorption is a maximum of 6% and the average compressive strength is at least 17 MPa for concrete quality B. This condition is evidenced by the acquisition of an average water absorption value of 0.531% for variation A and 2.2594% for variation B. Moreover, the average compressive strength value obtained is 27.238 MPa For variation A and 21.956 MPa for variation B. Polymer concrete in this study can be used as an alternative or substitute for conventional B-grade concrete used in construction.

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