The Enhancement of Compressive Strength of Cement-Based Composite Filled with LDPE/PET/Styrofoam Aggregates as Candidate for Breakwater Application

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Abstract. The composite of cement base matrix filled with LDPE/PET/Styrofoam plastic waste as aggregates has been successfully synthesized through a conventional mixing process. The highest density and lowest water absorbability of the composite are 2.06 g/cm³ and 6.02% respectively. SEM results show the distribution of sand aggregates were distributed evenly within the matrix. The PET has shown the tendency to form a spherical morphology. It is probably caused by the high adhesiveness of PET that induces the surface tension between PET and LDPE. The highest compressive strength value of the composite is 18.8 MPa.

Keywords: Plastic waste, LDPE/PET/Styrofoam, composite, breakwater, compressive strength.

1. Introduction

Indonesia is an archipelagic country with approximately 17,000 islands and 80,000 km of coastline (the area surrounded by beaches) which is a very intensive area utilized for industrial activities, ports, fisheries, and tourism. However, coastal conditions in Indonesia are quite dynamic against abrasion that is often caused by wind and sea wave activity or a combination of both due to weather and climate changes. This problem has an impact on the reduced feasibility of coastal areas (especially coastal areas with relatively large waves) to serve as tourism and settlement areas [1]. On the other hand, until now the problem of waste is still a very serious global problem. Even Indonesia itself is still working hard to overcome the problem of waste, especially plastic waste. Indonesia ranks in 2nd after China in the
contribution to the world's plastic waste. Plastic waste accounts for 16.31% of the total waste produced in Indonesia.

Both of these problems can be overcome simultaneously by utilizing an engineering waste plastic as a construction material that can be used as anchoring and breaking sea waves so that coastal abrasion can be reduced significantly. The principle of detention and breaking of ocean waves is to withstand, reduce, or eliminate the effects of winds, tides, and waves coming from seas or loose waters known as breakwater [2]. Breakwater structures can be made from massive or rigid structures and can also be of flexible structures (living plants, buoyant structures, and others). In addition, the breakwater structure can be designed and manufactured in a practical and economical manner by utilizing plastic waste which is then formed as a composite.

In this research, composite materials will be made using plastic waste for structural applications of retaining and breakwaters. Portland-based cement composites with LDPE/PET/Styrofoam plastic waste aggregate were tested and analyzed for their mechanical and physical properties. The results of this study are expected to be implemented in coastal/coastal areas with the amplitude and frequency of sea waves are relatively large as well as to be developed and optimized its potential as a tourist and residential areas.

2. Methods
The variable used in this research is the decrease of the coarse aggregate composition of LDPE / PET / Styrofoam plastic waste and the increase of sand aggregate with the change of cement composition. Table 1 describes the plastic waste composition of LDPE, PET, and styrofoam. Furthermore, Table 2 describes the variations of composite compositions of concrete cement binders with sand aggregates and plastic waste.

| No | Cement (%v) | Sand (%v) | Plastic Waste Aggregate (%v) |
|----|-------------|-----------|------------------------------|
| 1  | 25          | 0         | 75                           |
| 2  | 15          | 20        | 65                           |
| 3  | 20          | 20        | 60                           |
| 4  | 25          | 20        | 55                           |
| 5  | 15          | 30        | 55                           |
| 6  | 20          | 30        | 50                           |
| 7  | 25          | 30        | 45                           |
| 8  | 15          | 40        | 45                           |
| 9  | 20          | 40        | 40                           |
| 10 | 25          | 40        | 35                           |
| 11 | 25          | 75        | 0                            |

Making plastic waste aggregates is done with weighing the weight of the plastic (LDPE, PET, and Styrofoam) with scales according to the desired composition. Then plastic LDPE, PET, and Styrofoam put into a frying pan to be heated using heat from the stove until it becomes a liquid. Then stirring the plastic mixture performed using a spatula until the whole mixture is evenly mixed. Then melted plastic mixture poured into the container. The plastic waste aggregates then cooled until all parts become solid. After that aggregate plastic waste is removed from the container. Aggregate plastic waste is cut manually using a saw to get a standard coarse aggregate size.
2.1. Concrete composite making process
Making concrete composite specimens was done by weighing the weight of cement, sand, and plastic waste aggregate according to the desired composition. Cement, sand, and aggregate plastic waste that had been weighed are put into the bucket for stirring. The stirring process used a cement spoon by adding water little by little until the mixture of cement, sand, and plastic waste aggregate was evenly mixed. The mixed cement, sand, and aggregate of plastic waste were evenly poured into the mold. The concrete composites that had been printed are then d cooled to solid. Then the composite was removed from the mold.

2.2. Density characterization
This test was performed to determine the value of the mass of the composite type. The density of an object was the total mass divided by its total volume. An object with a higher density would have a lower volume than the same mass having a lower density. For density measurement using Archimedes method refer to standard ASTM C 134-95.

2.3. Water absorbability characterization
Water absorbability testing was used to calculate the change in the weight of an aggregate due to water absorbed into the pores compared to the dry conditions. Absorption would be obtained after soaking the dried specimen into the water for 24 hours. After that, the wet weight of the specimen is weighed. After weighing the wet weight, the specimen was then dried in the oven for 24 hours. After that, the specimens were weighed again to get the dry weight. The standard was used in this work was ASTM C642.

2.4. SEM characterization
This test was conducted to determine the composite morphology and its constituent, pore, particle size, and interfaces that occur on the composite. The specimens used for SEM testing are small parts of the composite. SEM testing was done using SEM test equipment belonging to ITS Material Engineering Department. The testing standard used was ASTM E986.

2.5. FTIR characterization
The FTIR test was performed to determine the functional groups formed on the composite. The functional group was indicated by different peaks. The specimen used for FTIR testing was a small part of the material being made. FTIR testing was performed using FTIR test equipment belonging to the Department of Materials Engineering ITS. The FTIR testing standard was ASTM E1252.

2.6. Compressive strength characterization
This test was performed to determine the compressive strength value of each composite. The compressive strength was the maximum weight of the broad unity, which caused the test object to be destroyed when loaded with a certain compressive force produced by the press machine. Strong press testing was done using standard SNI 03-0691-1996.

3. Results and Discussion
From Figure 1, it notes the trend of density test results has increased. The highest Density was tested specimen 11 with a density value of 2.06 g/cm³. The composition of this test specimen is 25% cement, 75% sand in the absence of a plastic aggregate in which the specimen 11 is the highest sand composition compared to other specimens. With the decrease in plastic waste aggregate composition and the increase in sand and cement composition, the value of density has increased. This is because the mass value of the type of small plastic waste aggregate is 0.89 g/cm³ when compared to the mass of the cement type, i.e., 3.2 g/cm³ and the sand of 2.4 g/cm³ so that the concrete composite type mass value increases. In addition, plastic waste aggregates that can undergo gap-gradation due after mixing plastic waste LDPE, PET, and Styrofoam with a melting process, the size of the plastic waste aggregate was obtained manually through cutting and cutting with grinding/sawing so that the
aggregate size of the plastic waste was not homogeneous and the potential for greater porosity in the concrete [3].

The addition of the amount of sand composition also led to an increase in the mass value of the type. This is because of the size of the sand in the form of small grains that become fine aggregates of concrete. Accordingly, the sand filled the concrete cavity and reduced the cavity so that it could also reduce porosity in the concrete [4]. Increasing composition of cement in the concrete also affected the value of the density of concrete composite. This was evidenced by the increasing value of the mass of specimen type with the increase of cement composition. The mass of cement type was the highest that is 3.2 g/cm$^3$ when compared with sand and aggregate of plastic waste. This results in more cement being used it would increase the density of the concrete composite itself [5].

![Figure 1. Density Test Result on Reduction of Aggregate Composition of Plastic Wastes.](image1)

![Figure 2. Chart of Results Water Absorbability Against Reducing the Composition of Plastic Waste Aggregates](image2)
Water absorbability of the test results shown in Figure 2 is obtained tendency of the drop-in percentage is the value of water absorbability composite. The effect of sand on the value of water absorption is a high value of water absorption caused by the content of SiO$_2$ in sand disproportionate (too much or too little). If the composition of SiO$_2$ is excessive, then it will react with the CaO present in the cement and with the addition of water to form CaOH$_2$. Calcium hydroxide causes the density of concrete composites to decrease due to the formation of air cavities. And when testing is done, the water will fill the existing air cavity so that the value of high concrete composite water absorption is certainly not good for concrete. Conversely, if the content of the sand is too little, then the bond of CaO is not optimal [6].

In addition, the effect of plastic waste aggregate by decreasing the composition of plastic waste aggregates also decreased the percentage of water absorbability. This corresponds to the increased composite density when the aggregate composition of the waste plastics decreases and the sand composition increases, the sand fills the empty cavities on the plastic waste aggregate and keeps the water from entering into the composite cavity.

Based on Figure 3, the yellow color shows composite FTIR test results with 25% Cement, 30% Sand and 45% Aggregate of plastic waste comprising LDPE, PET, and Styrofoam. The sample analysis was conducted at wavenumber 4000-500 cm$^{-1}$. The result is that there is a CH-alkane bond of LDPE at the highest wave peak of 2915 cm$^{-1}$, 2847 cm$^{-1}$, and 720 cm$^{-1}$. The peak that appears is a peak with strong intensity and in accordance with the peak that is read in the LDPE absorption area [7]. There are also bonds of PET with C=O carbonyl bonds at a wave of 1715 cm$^{-1}$. The CH alkane bond obtained at 1410 cm$^{-1}$ and 1342 cm$^{-1}$, CO ester bonds obtained at waves 1249 cm$^{-1}$, 1098 cm$^{-1}$, and 1017 cm$^{-1}$. And the aromatic bond CH is obtained at a wave of 873 cm$^{-1}$. Peaks that appear in accordance with peaks read in PET absorption areas.

Based on Figure 3, the red color shows the FTIR results of LDPE. The analysis was conducted at wavenumber 4000-500 cm$^{-1}$. From the analysis results obtained the alkane CH bond of LDPE at wave 2915 cm$^{-1}$, 2847 cm$^{-1}$, and 719 cm$^{-1}$ with strong intensity. The area of the frequency of CH alkanes is in the range of 2940-2840 cm$^{-1}$ with strong intensity and 725-720 cm$^{-1}$ for alkanes with numerous
branches [7]. In Figure 3, the blue color indicates the result of the FTIR PET. The sample analysis was conducted at wavenumber 4000-500 cm\(^{-1}\). The results of the analysis showed that the C=O carbonyl bond at a wave of 1715 cm\(^{-1}\) with a wave range of 1690-1760 cm\(^{-1}\) has a strong intensity. CH alkane bonds occurred at the waves of 1410 cm\(^{-1}\) and 1342 cm\(^{-1}\) with the wave range of 1340-1470 cm\(^{-1}\) having a strong intensity. The bonding of CO ester occurs at 1249 cm\(^{-1}\), 1098 cm\(^{-1}\), and 1017 cm\(^{-1}\) waves with a range of 1015-1300 cm\(^{-1}\) waves having a strong intensity. The aromatic bond CH occurred at a wave of 873 cm\(^{-1}\) with a wave range of 690-900 cm\(^{-1}\) possessing a strong intensity [8]. Moreover, results of the FTIR test found no new peak, which means no new chemical bonds are formed on composite concrete with LDPE and PET plastic waste aggregate. All peaks present in composite composers appear on peak FTIR composite test results.

![Figure 4](image)

**Figure 4.** SEM image of the sample with variation composition 25% cement/30% sand/45% aggregate plastic waste with magnification (a) 100x (b) 500x (c) 2000x

From SEM result figure 4(a) is 100 x magnifications LDPE/PET/Styrofoam waste plastic aggregates. It appears that a spherical ball with a smooth surface around it shows PET and LDPE. PET morphology forms a spherical ball, while the smooth surrounding surface shows LDPE. Diameter spherical ball will increase with increasing percentage PET composition [9]. Increasing the PET composition causes the surface to become rougher as the spherical ball becomes larger, whereas if the PET composition is slightly greater with the LDPE amount more than the surface will become smoother. The more the PET composition the LDPE will be dispersed with the wider diameter distribution. In this dispersed section avoid will be formed indicating that LDPE and PET are not attached to each other [10]. The absence of LDPE and PET is shown in Figure 4(b) which is a 500x magnification showing the interface between spherical ball PET and LDPE.

Figure 4(a) shows the morphology of sand covered by a cement binder. From the surface morphology of the specimen, it is seen that the sand distribution is evenly distributed as evidenced by the rough surface morphology of the specimen. The shape of sand grains shows a flat shape, and also there are not
irregular. The uniform spread of the sand filler will improve the mechanical properties of the composite material while the void and spherical ball shape affect the level of water absorption.

Figure 4(c) is the result of SEM with 2000x magnification. The gray one is binder cement. While the light-colored matrix is LDPE and spherical ball is PET. At this magnification, it is clear that the interface is limiting between cement and plastic waste aggregates. Where LDPE and PET itself also has an interface that indicates the two types of plastic is not fused. The mechanism of the interface on LDPE and PET is due to the non-polar LDPE and polar PET properties. So that because of the different polarity of LDPE and PET causes LDPE and PET cannot converge. The interface mechanism of LDPE and PET is due to the surface tension between LDPE and PET causing LDPE and PET do not dissolve during the melting process. Non-polar molecules cannot balance the molecular force on the polar surface, so there is an interface between LDPE and PET.

![SEM Images](image-url)

**Figure 5.** SEM Results Variations 25% Cement and 75% Sand with Magnification (a) 100x (b) 500x (c) 2000x

Figure 5 shows SEM results on a variation of 25% cement and 75% sand composition in the absence of aggregate plastic waste. Compared with the SEM results of 25% cement composition, 30% sand and 45% plastic waste aggregate in Fig. 4, then on the SEM results of cement and sand there are more voids seen in Fig. 5(a) which is 100 x magnifications. On the magnification of SEM results as in Figure 5(b) and (c), the surface texture of the semen SEM and sand yields a coarse texture and there is a flat form which is sand covered with cement. When compared with SEM results in Fig 4, on the SEM result of Fig 5 there is no spherical ball provided by PET. The surface texture given by the filler on the composite, in this case, is the sand and the plastic waste aggregate.
Figure 6. Graph of Compressive Strength Test Result on Aggregate Composition Reduction on Plastic Wastes

From Fig 6, it can be seen that the trend that occurs in the testing of compressive strength tends to increase. However, there was a decrease in the trend in composition 8, namely the composition of 15% cement, 40% sand and 45% plastic waste aggregate. The cause of this decline is the occurrence of cracks due to depreciation. This crack occurred in the first 1 to 8 hours after the concrete composite is printed. Depreciation occurred due to the loss of water content from the cement mixture so that the hydration of cement does not occur maximally so that shrinkage would occur. On the other hand, concrete tended to expand when moistened (increasing volume can be proportional to the amount of concrete shrinkage). Meanwhile, plastic waste aggregate also could not bind naturally with cement or sand. Therefore, the optimal cement composition was required to obtain maximum binding so that it would increase the compressive strength value of composite concrete. This is the case with the cement composition of 20% and 25% in which the increase in the strong value of the concrete occurs.

Sand also affected the composite strength of concrete press. The increased sand composition causes the compressive strength value of concrete to increase. This is due to the relatively small size of the sand filling the cavities in the concrete thus increasing the concrete density and the compressive strength of the concrete. In addition, sand has a higher strength than plastic waste aggregate, so with the addition of sand and reduction of the aggregate composition of plastic waste, the compressive strength value of composite concrete will increase [9].

From the results of testing the compressive strength, it is known that the decrease of the aggregate composition of waste plastics causes an increase in compressive strength. This can occur because the plastic waste aggregate surface tends to smooth and slippery so that the bond between concrete composite propulsion particles is less strong when compared with normal concrete. In addition, in terms of aggregate strength, plastic waste was softer when compared to aggregates of gravel or crushed stone commonly used as a coarse aggregate in the manufacture of normal concrete [10]. So that by decreasing the composition of the aggregate of plastic waste there will be an increase in the value of the concrete composite compressive strength.

Basically, plastic and sand cannot be attached, and it takes a chemical compound to attach it. The larger the size and number of plastic aggregates on the concrete will reduce the strength of the concrete. Accordingly, the less the plastic composition as an aggregate there will be an increase in the compressive strength value of concrete. The pattern of failure that occurs in the concrete composite of the compressive strength test is the crack around the sample which can be caused by the aggregate
composition of the large plastic and sand waste resulting in the reduction of bonding on the concrete composite [11].

4. Conclusion
Based on the discussion above, it can be concluded that LDPE/PET/Styrofoam plastic waste aggregate filler has affected the physical properties of composite materials. The reduction of plastic waste aggregate fillers tends to improve the physical properties of composite materials. The maximum density of the composite material is 2.06 g/cm³. The lowest water absorbability percentage is 6.02%. The reduction of plastic waste aggregate fillers also tends to improve the mechanical properties of composite materials. The maximum compressive strength of the composite material is 18.8 MPa. Furthermore, the lowest percentage of mass loss which occurs in the composite material is 0.03%.

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