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The Effect of Fly Ash Based Geopolymer Aggregate Using Crushing and Pelletization Methods on the Mechanical Properties of Concrete

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Abstract Over the last decade, there has been significant growth in the world in infrastructure developments, leading to an increase in the consumption of materials. One of the most commonly used materials in the construction industry is concrete which is made up of several constituent elements including coarse aggregates. The availability of these aggregates in nature was observed to have been reduced significantly, thus leading to the search for alternative sources. The production of artificial aggregates through the geopolymerization process is an example of this alternative source. The process involves reacting materials containing high content of silica and alumina such as fly ash with an alkaline activator. Therefore, this study is aimed at analyzing the effect of fly ash-based artificial aggregates produced using crushing and pelletization methods on the mechanical properties of concrete. The ratio of the mass of fly ash to the mass of alkali activator in the geopolymer artificial aggregate composition is 3:1. The mass ratio of Na_2SiO_3 to NaOH was 2.5:1, the concentration of NaOH was 15 M, and the addition of sand was 15% of the fly ash mass. The concrete composition for the three types of aggregate, namely natural aggregate, crushing aggregate, and pelletization aggregate, uses constituent materials with the same volume with adjustments, type, and uses the same manufacturing method. Natural aggregate concrete has the highest compressive strength and tensile strength of concrete, followed by pelletization of aggregate concrete, then crushing of aggregate concrete. The compressive strength values of the 28-day-old concrete for the three aggregates were respectively 28,976 MPa, 25,582 MPa, and 23,418 MPa and the tensile strength values for the 28-day-old concrete for the three aggregates were respectively 2,917 MPa, 2,641 MPa, and 2,323 MPa. Since the design compressive strength value of pelletized aggregate concrete is achieved, geopolymer aggregate using the pelletization method can be used as an alternative to natural aggregate.

Keywords Aggregate, Fly Ash, Pelletization, Crushing, Geopolymer

1. Introduction

Infrastructural development is growing significantly globally in recent decades, thereby leading to an increase in the consumption of construction materials. One of the most commonly used materials in the contemporary construction industry is concrete which is normally produced through the combination of Portland or other types of cement, fine and coarse aggregates, water, and several other ingredients or admixture. This simply means concrete is composed of a combination of water, fine granules (sand), coarse granules (crushed rock), and cement. Different combinations of binders and admixtures are sometimes added to improve the quality of the concrete [1]. Concrete, as the material most often used in the construction industry, has very high compressive strength and is considered important in constructing buildings, bridges, roads, condominiums, apartments, and several other infrastructures.

Aggregates such as gravel, crushed stones, and sands are basic materials in construction through their mixture with binders to form concrete and asphalt [2]. They can be classified into coarse such as gravel and fine aggregates in the form of sand. Coarse aggregates are further classified into natural and artificial types. Continuous technological development was observed to have reduced the volume of natural aggregates on earth, thereby leading to the need to find alternative sources for replacement. This is necessary due to the importance of coarse aggregates or crushed stones to the specific gravity of concrete. Moreover, the combination of fine and coarse aggregates is the component most widely used to manufacture concrete as indicated by their contribution of 60% to 70% to the total volume [3]. Several types of natural rocks such as limestone [4], basalt [5], and gravel [6] are usually used in the concrete industry based on their geological conditions. The importance of these materials is associated with the need for up to 60% as filler in concretes. A previous report showed that the global consumption of aggregates in the construction sector was over 48.3 billion tons/year in 2015 and the figures were expected to continue increasing by 5.2% per year [7]. Meanwhile, the volume of natural aggregates available is observed to be reducing due to increased demand and this means there is a need for alternative sources such as artificial aggregates.

Geopolymer artificial aggregates can be produced from waste materials including fly ash derived from the combustion of coal [8]. The process includes synthesizing through a chemical reaction called polymerization, which occurs between an aluminosilicate material, such as fly ash or blast furnace slag, and an alkaline activator [9, 10]. Fly ash is a waste material generated from the combustion process [11]. Furthermore, the production of artificial aggregates involves mixing fly ash with an alkaline activator employing crushing and pelletization techniques.

Geopolymer is normally produced by polymerizing inorganic materials containing significant amounts of silica (Si) and aluminum (Al) [12]. These materials include industrial waste such as fly ash, iron blast furnaces, and bottom ash obtained as residue from burning coal. However, there is presently no optimal utilization of fly ash as a substitute for cement or artificial aggregates in geopolymers. As previously stated, this can be achieved through the addition of alkaline activators including sodium hydroxide (NaOH) and sodium silicate (Na_2SiO_3) solutions to fly ash to trigger the polymerization process. The reaction normally leads to the formation of strong monomer bonds. This simply means the precursors are activated by alkali through their dissolution in (SiO_4) and (AlO_4) monomers [13].

Artificial aggregates are specifically produced to decrease the usage of the natural aggregates observed to be currently depleting. The process involves using natural materials such as fly ash that contain a high volume of silicon and aluminum elements as a building block for the geopolymer-made aggregates. Moreover, the characteristics of these aggregates can further be improved by combining fly ash with sand during the production process. It is important to further emphasize that fly ash is normally produced by burning coal and has a high content of silica and lime. When this material is mixed with water, its fine particles react with silica oxide and calcium hydroxide to produce substances that are able to bind and exhibit cement hydration processes [14]. The methods are often used to produce artificial aggregates include crushing and pelletization.

Crushing is a method that involves reducing the size of materials with force. The application of this method to produce artificial aggregates has some stages which include mixing, casting, crushing, and curing [2]. The first stage is mixing the fly ash (FA) and alkaline activator (AA) after determining the suitable FA/AA ratio and alkaline activator ratio (Na_2SiO_3/NaOH) [12, 15, 16]. The process usually requires a special mixer to ensure the materials are mixed efficiently.

The crushing technique was explored in this study due to its good prospect for massive industrial production. This was achieved by first producing geopolymer cubes with the dimension of 100 × 100 × 100 mm using one-part geopolymer technology followed by the crushing of the cubes into coarse aggregates with angular shapes [17].

The application of the pelletization method to produce artificial aggregates depends on some factors such as the slope of the granulator, rotational speed, stirring time, and water content. These factors can be varied to obtain different artificial aggregates. The process usually involves spraying the alkaline activator during the mixing process in the granulator followed by curing using different methods [2]. A variation of this method is cold-bond pelletization which is normally applied to dry-powdered fly ash.

This method allows the agglomeration of fly ash particles in an inclined rotating pan at room temperature to produce fly ash pellets. The process requires using water as a wetting agent while Portland cement and/or lime serve as the binder. Moreover, the method requires much lower energy consumption to produce artificial light aggregates.

Type F fly ash was mixed with NaOH and Na_2SiO_3 [18] at a Na_2SiO_3/NaOH ratio of 2.5 and a concentration of 10 M NaOH [19]. The aggregate was formed using a pan granulator with a depth of 100 mm and a diameter of 450 mm. Moreover, the granulator angle was 45° [20-22], the rotation duration was 15 minutes, and the speed was maintained at 10 radians per minute (rpm). The fly ash was rotated gradually in the granulator pan and was sprayed with an activator during the process. The aggregates produced were uniformly spherical and the size of the pellets depended on the amount of activator used.

In this research, fly ash which is the precursor for artificial geopolymer aggregates comes from PT Pupuk Sriwidjaja. The manufacturing of artificial geopolymer aggregates uses two methods, namely crushing and pelletization methods. The ratio of the mass of fly ash to the mass of alkali activator in the geopolymer artificial aggregate composition was 3:1. The mass ratio of Na_2SiO_3 to NaOH was 2.5:1, the concentration of NaOH was 15 M, and the addition of sand was 15% of the fly ash mass.

The geopolymer artificial aggregate composition uses sand as much as 15% of the fly ash mass with the aim of reducing the slippery surface of the aggregate. The slippery surface of the aggregate is caused by the alkali activator content which does not react with the precursor. The rougher surface of artificial geopolymer aggregate when sand is added will increase friction and interlocking between aggregate and binder.

After the artificial geopolymer aggregate is made using the crushing and pelleting methods, the artificial aggregate is dried in an oven at 80 ℃ for 24 hours and then cured at room temperature. Geopolymer aggregates made from artificial fly ash were tested for their aggregate properties and compared with natural aggregates. Geopolymer aggregates and natural aggregates in this research will be used as concrete building blocks. This research uses the same type of material and the same volume of material that makes up concrete. Concrete made with geopolymer aggregates and natural aggregates is tested for its mechanical properties, namely compressive strength and tensile strength of concrete.

2. Materials and Methods

This study was used to produce artificial geopolymer aggregates using the crushing and pelletization methods. The constituent materials used include fly ash, alkaline activator, and fine aggregates. Moreover, concrete was later produced using three different types of coarse aggregates including geopolymer aggregates from crushing, geopolymer aggregates from pelletization, and natural aggregates. The mechanical properties of the concrete produced using these aggregates were later compared.

2.1. Materials Utilized to Produce Geopolymer Artificial Aggregates

2.1.1. Fly Ash

The fly ash used in this study was obtained from PT. Pupuk Sriwidjaja Palembang. This material was tested using X-Ray Diffraction (XRD), X-Ray Fluorescence (XRF), and Scanning Electron Microscope (SEM) to determine its characteristics and class [23,24,25]. The chemical composition (XRF) of the fly ash is presented in Table 1 while the results of SEM and XRD are shown in Figures 1 and 2, respectively.

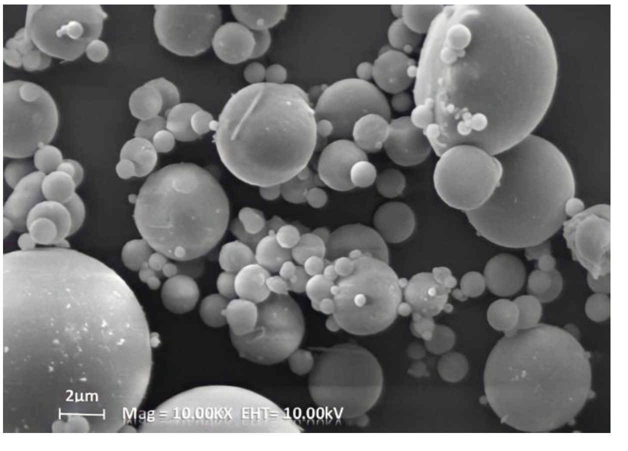

Figure 1. SEM image of the fly ash used in this study [2]

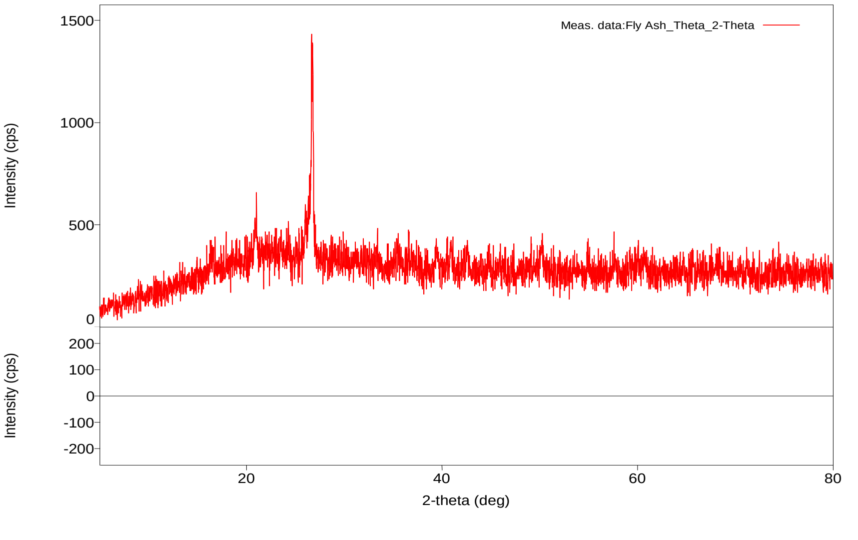

Figure 2. XRD of the fly ash used in this study [2]

Scanning Electron Microscope (SEM) is an electron microscope test that produces images of samples by scanning the surface with an electron beam. The image is created based on the detection of new electrons or reflected electrons that appear on the sample surface when scanned with an electron beam. The reflected electrons then have their signal amplified and the amplitude is enlarged and displayed in gradations of dark and light on the monitor screen. Most fly ash granules are spherical as shown in the SEM with 10,000× magnification in Figure 1. This shape allows the fly ash to react rapidly with other particles during the production of geopolymer mixtures.

Table 1. Chemical composition (XRF) of the fly ash used in this study

Components	% in mass
MgO	0.2866
Al_2O_3	18.6427
SiO_2	36.3552
P_2O_5	0.2055
SO_3	0.2849
K_2O	0.7973
CaO	2.9143
TiO_2	0.9807
MnO	0.0932
Fe_2O_3	5.7413
CuO	0.0116
ZnO	0.0246
SrO	0.0931
Y_2O_3	0.0095
ZrO_2	0.0555
Balance	33.5039

X-Ray Fluorescence (XRF) is a test of the elemental content of materials. In this study, the material tested for XRF was fly ash. XRF is used to determine the concentration of an element by using the wavelength and number of X-rays that are re-emitted after a material element is exposed to high-energy X-rays. XRF test was conducted to determine the chemicals contained in the fly ash. This was considered important due to the influence of the chemical compositions of the fly ash on the strength of the geopolymer artificial aggregates to be produced. The results classified the fly ash as type C according to the ASTM 618 standard [25] because it contained 50% $\leq SiO_2 + Al_2O_3 + Fe_2O_3 \leq$ 70%.

X-Ray Diffraction (XRD) is a Testing of fly ash content with the principle of checking the dominance of crystal content in fly ash. The crystal content in fly ash should not dominate because it can interfere with the material casting process, because fly ash will not react with other materials. The purpose of XRD is to determine the crystal system, explain the lattice parameters, the arrangement of atoms in the crystal, the type of structure, orientation and grain size. The diffraction image obtained when carrying out XRD analysis of fly ash is shown in Figure 2. It can be seen that the fly ash crystal peak is very small, which appears at a diffraction angle of 26.7° with an intensity of 1433.333 cps. This shows that the fly ash used in this study has an amorphous structure.

2.1.2. Alkali Activator

Alkaline activator solution is an important part of the synthesis and strength development of geopolymer mortar [26-29]. Sodium hydroxide (NaOH) and sodium silicate (Na_2SiO_3) are usually used as alkali activators [20-23] to serve as the substances or elements causing other elements to react [30, 31]. These activators normally contain NaOH and silica, which is a strong acid with the ability to react with a strong base. The Na_2SiO_3 can accelerate the polymerization reaction while NaOH reacts with the Si and Al in the fly ash to produce strong polymer bonds. Therefore, the alkaline activator [32] was prepared by mixing a 15 M NaOH solution with a Na_2SiO_3 solution and the mixture was left for 1 day to achieve equilibrium before application. The NaOH solution with 1 M concentration was produced by inserting 40 grams of NaOH flake into a measuring cup, adding distilled water to make the solution become 1 liter, and stirring the solution up to the moment it was well blended. The process was repeated to achieve the desired concentration [33]. The dissolution process was conducted for several hours due to the high concentration of the NaOH solution in order to release heat and allow further mixture with the sodium silicate. The mass ratio of fly ash to alkali activator used for all the methods to produce the geopolymer-made aggregate mixture in this study was 3:1, the mass ratio of Na_2SiO_3 to NaOH was 2.5:1, and the concentration of NaOH was 15 M.

2.1.3. Fine Aggregate

Tanjung Raja sand with a size ranging from 4.75 mm - 0.075 mm was used as fine aggregates for the whole investigation. The sand was used in saturated surface dry (SSD) conditions to avoid water absorption from the alkaline activator solution.

2.2. Geopolymer Artificial Aggregates Production

The artificial aggregates were produced by first preparing the alkaline activator solution followed by the insertion of the fly ash into the granulator pan. For the pelletization process, a granulator pan of diameter 60 cm and depth 20 cm was used, with a tilt angle of 55° and a speed of 30 rpm. The pan was rotated while the alkaline activator was allowed to drip for 15 min.

For the crushing method, the same materials were mixed, placed into a mold, hardened for an hour in the oven, de-molded, and placed in a stone crusher.

The curing process used in this study was heating in an oven at 80 ℃ for 24 h, after which the materials were allowed to cool at room temperature.

The artificial aggregates produced from the pelletization method were generally round because the mixture was rotated using a granulator container. The texture of the coarse aggregate was also not slippery. Meanwhile, those produced using the crushing method had crushed stone angle shapes. The size of the aggregates produced using the two methods ranged from 2.36 mm to 25.4 mm, with the average size of the largest found to be 4.75 mm to 12.5 mm. The natural coarse aggregate used was obtained from Merak with the same gradation as the geopolymer artificial aggregates produced.

2.3. Concrete Fabrication

Several studies explain that concrete strength is influenced by several parameters, both compressive strength and tensile strength of concrete, especially parameters related to the constituent materials and methods used in making concrete. The factors that influence the strength of concrete depend on the type and dosage of cement, water to cement ratio (w/c), type and size of aggregate, fine aggregate fraction, total aggregate volume [34]. Then the method for making concrete that affects strength is curing which is carried out when the constituent materials are mixed homogeneously and hardened.

In this study, the concrete composition for three types of aggregates used constituent materials with the same volume and type and used manufacturing methods with the same treatment. They all used the same type and dosage of cement, w/c ratio, volume of fine and coarse aggregate, gradation of coarse aggregate, type of fine aggregate, and curing method. One thing that differentiates the concrete specimens made in this research is the type of coarse aggregate used.

Since the material that differentiates the concrete used in this research is the coarse aggregate type, properties were tested on the three types of aggregate. The properties tests carried out are moisture content, bulk specific gravity, absorption, and aggregate impact value (AIV).

The design compressive strength (F'c) used to produce the concrete in this study was 25 MPa. The concrete was fabricated using three different types of aggregates including those produced using crushing and pelletization methods as well as the natural coarse aggregates mixed with OPC Baturaja cement and Tanjung Raja sand.

The same binder mixture was used for all the aggregates with adjustments to their respective specific gravity, moisture content, and absorption rate. The design mix formula used to produce the concrete for each type of aggregate is listed in the following Table 2.

Table 2. Design Mix Formula

Concrete Mix Design	Natural Aggregate concrete	Crushing aggregate concrete	Pelletization aggregate concrete
OPC Baturaja (kg/m^3)	592,105	592,105	592,105
Sand Ex. Tanjung Raja (kg/m^3)	362,825	416,747	416,747
Aggregate (kg/m^3)	1057,701	972,990	1013,159
Water (kg/m^3)	218,618	311,907	271,739

The concrete specimen was cast using a standard cylindrical mold with a diameter of 100 mm and a height of 200 mm and later hardened by wrapping the surface with plastic wrap. The concrete was left at room temperature until the compressive and split tensile strength tests were conducted at the ages of 3, 7, and 28 days.

3. Results and Discussion

In this research, the concrete composition for the three types of aggregate, namely natural aggregate, crushing aggregate, and pelletization aggregate, uses constituent materials with the same volume, type, and uses the same manufacturing method. The parameter that differentiates the concrete specimens made in this research is the type of coarse aggregate used. Then the coarse aggregate properties were tested. The type of coarse aggregate is the key material that differentiates the results of the compressive strength and tensile strength of concrete. The compressive and tensile strengths were used to determine the mechanical properties of concrete. The tests were based on ACI 318 [34] and conducted using 5 pieces of each specimen variation.

3.1. Coarse Aggregate Properties Test

The four types of coarse aggregate properties tested in this research are moisture content, bulk specific gravity, water absorption, and aggregate impact value (AIV). Each property aggregate is tested 3 times and then the average value from the 3 test is taken. The properties of the coarse aggregate tested in this study are shown in the Table 3.

Table 3. Properties of Three types of Coarse Aggregate Test Results

Aggregate Properties	Natural aggregate	Crushing aggregate	Pelletization aggregate	Testing standards
Moisture Content	1,668%	11,907%	4,080%	ASTM C566 [35]
Bulk Specific Gravity	2,539	2,056	2,058	ASTM C127 [36]
Water Absorption	3,940%	17,065%	5,382%	ASTM C127 [37]
Aggregate Impact Value (AIV)	1,46%	17,60%	8,610%	BS 812-112 [38]

Based on the test results and moisture content calculations, it was found that the average percentage of moisture content of natural coarse aggregate, crushing aggregate, and pelletization aggregate was 1.668%, 11.907%, and 4.080%, respectively. Based on ASTM C566 coarse aggregate have good water content in the interval 0.5% - 2%, but only natural aggregate meets the interval as coarse aggregate with good water content.

The test results and calculation of the average bulk specific gravity values for the three types of aggregate, namely natural coarse aggregate, crushing aggregate, and pelletization aggregate were 2,539, 2,056, and 2,058 respectively. Coarse aggregate can be said to be a good aggregate for the bulk specific gravity parameter when it is in the value interval 1.60-3.20 based on ASTM C127. The average value of bulk specific gravity for the three types of coarse aggregate meets the standards used.

The average water absorption of the three types of coarse aggregate, namely natural coarse aggregate, crushing aggregate and pelletization aggregate, respectively, is 3,940%, 17,065%, 5.382%. The absorption value that meets the standards in ASTM C127 with a limit of between 0.2% -4% is only natural aggregate.

Based on the AIV test results, the percentage of AIV in three types of coarse aggregate, namely natural coarse aggregate, crushing aggregate and pelletization aggregate, is respectively 1.46%, 17.60%, 8.61%. Based on BS 812-112, the limit for a good AIV value is < 30%, so from the test results it can be concluded that the three types of coarse aggregate to be used meet the BS 812-112 standard, which means they have strong resistance to impact.

Moisture content, bulk specific gravity, water absorption, and AIV values that meet the standards and do not meet the standards used for the three types of coarse aggregate influence the results of achieving the compressive and tensile strength of the concrete.

3.2. Compressive Strength Test

The compressive strength was tested by evaluating the durability of concrete under the compressive force generated by the testing machine. This parameter is important to determine the quality of concrete and the suitability of a building for residential purposes. The results are obtained for the three different types of aggregates used based on the JMF planning. The results obtained from testing the compressive strength of concrete are presented in Figure 3 below.

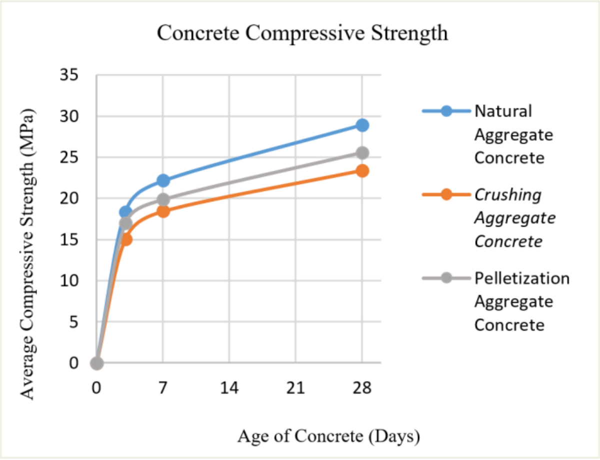

Figure 3. Concrete Compressive Strength Test Results

The concrete produced using natural aggregates was found to have the lowest compressive strength of 18.327 MPa at 3 days and the highest was 28.976 MPa at 28 days as presented in Figure 3. Meanwhile, the values for the concrete produced using aggregates from the crushing method were 15.018 MPa and 23.418 MPa, respectively. This indicated a decrease of 18.055% at 3 days and 19.181% at 28 days compared to the natural aggregates. Moreover, the weight produced from the crushing concrete was discovered to be lighter than the natural aggregate concrete by 9.530% for 3 days and 10.122% for 28 days. The results also showed that the lowest concrete compressive strength for the pelleted concrete was 16.927 MPa at 3 days while the highest was 25.582 MPa at 28 days. This indicated a reduction of 7.639% at 3 days and 11.713% at 28 days of age compared to the natural aggregates. The data used for the comparison were obtained by taking the average of five specimens for each variation. Furthermore, the compressive strength value was observed to be influenced by several factors, specifically the properties of the materials. It was concluded that the concrete produced using fly ash-based geopolymer aggregates through the crushing method had lower compressive strength and characteristics than the natural aggregate concrete.

The compressive strength of concrete depends on the water to cement ratio, degree of compaction, ratio of cement to aggregate, bond between mortar and aggregate, and grading, shape, strength and size of the aggregate. For normal concrete, the crack growth is mainly around the cement paste or at the aggregate/cement paste interfacial zone. The strength of concrete at the interfacial zone essentially depends on the integrity of the cement paste and the nature of the coarse aggregate [39].

Coarse aggregate is one of the main factors influencing the compressive strength of concrete. In this research, the composition and type of material making up the concrete used the same volume, the same type of material, and the same mixing and curing method. One difference is the type of coarse aggregate used. Because only the type of coarse aggregate is different, the aggregate properties are tested which will then be analyzed for the quality of the concrete produced.

The coarse aggregate used in this research was designed to have the same size gradation but have different shapes. The natural coarse aggregate used has an irregular and angular shape. This angular shape produces interlocking between aggregates, thereby increasing the compressive strength of concrete that uses natural aggregates. Concrete made by crushing aggregates has the lowest compressive strength at ages 3, 7 and 28 days. Crushing aggregate has a shape similar to natural aggregate, but some of the crushing aggregate produced has a flat shape and causes the aggregate to become brittle and break easily when subjected to loads and impacts. Pelletization aggregate has a round shape. This round shape causes a lack of interlocking between aggregates. The lack of interlocking between aggregates causes the compressive strength of concrete to be lower than concrete that uses natural aggregates.

The moisture content value of coarse aggregate affects the quality of concrete, which can be seen in Table 3 and Figure 4. The moisture content value of aggregate that is not included in the standard interval used has a lower compressive strength value. The further the moisture content value is from the standard interval, the lower the compressive strength. This can be shown in the moisture content value of the crushing coarse aggregate which has the value farthest from the interval, resulting in the lowest compressive strength of the three types of aggregate. On the other hand, the moisture content value that falls within the standard interval has the highest compressive strength for each age of concrete.

Bulk Specific gravity is often correlated to the volume of pores and solid materials in bulk. The lower the bulk specific gravity value of the aggregate, the greater the pore volume of the aggregate [40]. A large pore volume in coarse aggregate indicates a lower level of aggregate density. The density of the materials that make up concrete has a clear correlation with the level of strength produced by the concrete. The three types of aggregate meet the standard specific gravity value intervals used in this research. Natural aggregate which has the highest specific gravity value also has the highest concrete compressive strength value and crushed aggregate which has the lowest specific gravity value has the lowest concrete compressive strength.

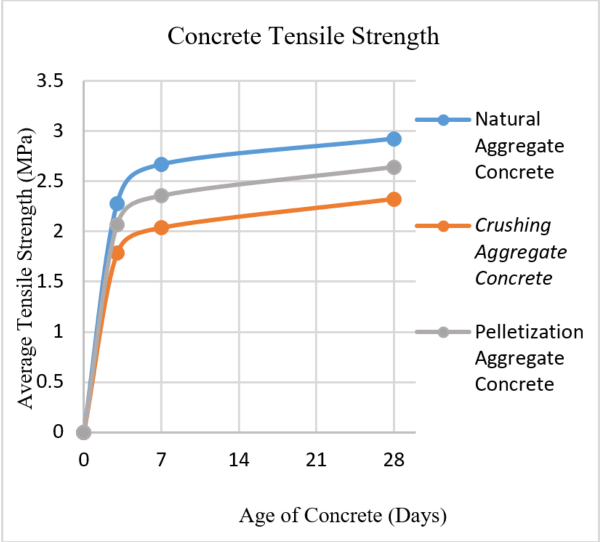

Figure 4. Concrete Tensile Strength Test Results

Water absorption of coarse aggregate has an influence on the compressive strength of concrete. The water absorption value influences the amount of water that will react with the cement. High absorption will absorb water that should be used for the hydration process in the concrete, instead it will be absorbed by the aggregate. So the amount of water that should react with cement in the concrete hydration process is not appropriate. The highest compressive strength value of concrete with natural coarse aggregate has a water absorption value that falls within the standard test interval used. Meanwhile, crushing aggregates and pelletization aggregates which are not standard have concrete compressive strength values below concrete with natural aggregates.

AIV value is a measure that determines its resistance to sudden impact or shock. The lower the aggregate AIV value, the stronger the aggregate's resistance to collisions or shocks. Natural aggregate has the lowest AIV value and has the highest compressive strength of concrete. This shows that the stronger the coarse aggregate withstands impacts and shocks, the higher the compressive strength of the concrete using that aggregate, and vice versa.

The three types of aggregates were tested for properties and then analyzed for the compressive strength obtained by concrete with natural aggregates, crushing aggregates and pelletization aggregates. Natural aggregate has coarse aggregate property values that fall within the standard interval used so that it has the highest compressive strength value and exceeds the design compressive strength. Crushing aggregate has property values that fall within the standard interval, only bulk specific gravity, while the other property values are relatively far from the standard interval when compared to the other two coarse aggregates. Crushing aggregate has the lowest concrete compressive strength for each age of concrete, namely 3, 7 and 28 days. Pelletized aggregates have coarse aggregate property values that fall within the standard interval, namely bulk specific gravity, while the other properties do not enter the standard range, but are relatively close to the standard interval used, so the concrete has a compressive strength that is higher than concrete with crushing aggregate but lower than natural aggregate. and the compressive strength value obtained is in accordance with the planned compressive strength, namely 25 Mpa.

3.3. Tensile Strength Test

The split tensile strength test was conducted to determine the tensile capacity of the concrete. This was achieved by adopting the ACI 318 standard such that the cylindrical specimens were placed in a horizontal position and provided with a load on both sides with length L. The force was distributed evenly across the entire surface of the cylinder and increased gradually until the maximum value to split the cylinder was attained. The results obtained from this process are presented in the following Figure 4.

The results presented in Figure 4 showed that the lowest tensile strength for the natural aggregate concrete was 2.280 MPa at 3 days while the highest was 2.917 MPa at 28 days. The values for the concrete made using crushed aggregates were found to be 1.782 MPa and 2.323 MPa, and this indicates a reduction of 21.860% and 20.364% respectively compared to the natural aggregate concrete. The split tensile strength of the natural aggregate concrete was found to be 12.442% of the compressive strength at 3 days and 10.066% at 28 days. The values were recorded to be 11.864% and 9.918% respectively for crushed aggregate concrete.

The lowest split tensile strength of the pelleted aggregate concrete was recorded to be 2.068 MPa at 3 days while the highest was 2.641 MPa at 28 days, and this indicates a reduction of 9.302% and 9.455% respectively compared to the natural aggregate concrete. The split strength value of the pelleted aggregate concrete was found to be 12.218% of the compressive strength at 3 days and 10.322% at 28 days. The results further showed that the weight produced by the crushed aggregate concrete was lighter than the review concrete by 9.929% at 3 days and 11.124% at 28 days. These values were obtained by taking the average of the results for the tensile strength test conducted on three specimens for each variation. It was concluded that the split tensile strength of the concrete produced ranged between 9% and 15% of the compressive strength value. The concrete produced using fly ash-based geopolymer artificial aggregates through the crushing method was observed to have lower split tensile strength than the natural aggregate concrete.

Concrete compressive strength identifies the quality of concrete. Each increase in compressive strength is only accompanied by a relatively small increase in tensile strength. The tensile strength value is between 9% - 15% of the compressive strength [41]. The tensile strength of concrete from the three types of coarse aggregate used has the same pattern of increasing values as the compressive strength. This is because the tensile strength value of concrete is between 9% - 15% of the compressive strength of concrete.

The tensile strength value of concrete has a clear correlation with the compressive strength of concrete. So the tensile strength of ordinary concrete is influenced by the same parameters as the compressive strength of concrete. In this research, the same type of material, volume of material, mixing and curing methods were used. The difference between the concrete in this research is the type of coarse aggregate used.

The three types of aggregate were tested for properties and then analyzed for the tensile strength obtained by concrete with natural aggregate, crushing aggregate and pelletization aggregate. Natural aggregate has coarse aggregate property values that fall within the standard interval used so that it has the highest tensile strength value among the three types of concrete. The crushing aggregate has property values that fall within the standard interval, only bulk specific gravity, while the other property values are relatively far from the standard interval when compared to the other two coarse aggregates, so it has the lowest concrete tensile strength of each concrete age. Pelletization aggregates have coarse aggregate property values that fall within the standard interval, namely bulk specific gravity, while the other properties do not fall into the standard range, but are relatively close to the standard interval used in this research, so the concrete has a tensile strength that is higher than concrete with crushed aggregate but lower from natural aggregates.

4. Conclusions

Based on the results and analysis carried out it can be concluded that:

1. Natural aggregate concrete has the highest compressive strength of concrete, followed by pelletization aggregate concrete, then crushing aggregate concrete. The compressive strength values of the three aggregates are 28,976 MPa, 25,582 MPa, and 23,418 MPa respectively.
2. Natural aggregate concrete has the highest tensile strength of concrete, followed by pelletization aggregate concrete, then crushing aggregate concrete. The tensile strength values of the three aggregates are 2,917 MPa, 2,641 MPa, and 2,323 MPa respectively.

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