Tensile Strength and Absorption Analysis of Hybrid High Quality Concrete Using Cement Replacement Additives Substitution, Aggregate Substitution and Nanomaterial Iron Ore

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Abstract. High quality concrete is defined as concrete which has a required compressive strength greater than 41.4 MPa. One disadvantage of high quality concrete is the high cost of production. Therefore alternative economical materials such as coal fly ash, palm shells, and pozzolan sand are used as alternative replacement materials. This study aims to determine the value of split tensile strength, flexural tensile strength, and absorption by using alternative substitute materials as substitute additives, fine aggregates, and coarse aggregates and the addition of nanomaterial iron ore fillers with seven different types of variations. The specimens for testing the split tensile strength in the form of cylinders measuring 30 cm high and 15 cm in diameter were 42 pieces, the specimens for testing flexural tensile strength in the form of beams measuring 15 cm x 15 cm x 60 cm were 42 pieces, and the specimens for absorption testing were in the form of 42 cubes in size of 5 cm x 5 cm x 5 cm. The tests were carried out at 28 days and 56 days. The results showed that high quality concrete using variations of BMT-APPP with the result of flexural tensile strength at 28 days is 5.19 MPa and at the age of 56 days with a value of 5.58 MPa. Maximum tensile flexural strength results obtained in high quality concrete using BMT-APPP variations, namely the results of split tensile strength at 28 days 5.73 MPa and at the age of 56 days with a value of 6.11 Mpa. Absorption of normal high quality concrete at 56 days is 4.63%, greater than hybrid high quality concrete with various variations. From the test results it can be concluded that BMT-APPP is the best variation of this study.

1. Introduction
Concrete has always been known as a material with high compressive strength, easily formed, easily produced locally, durable, and economical. Based on SNI PD-04-2004-C high quality concrete is concrete with the required compressive strength that is equal to 40 MPa - 80 MPa. While listed in SNI 03-6468-2000, high strength concrete is defined as concrete which has a compressive strength that is required to be greater than 41.4 MPa. But, one disadvantage of high quality concrete is the high cost of production.

Based on the current conditions in the field, especially in the Aceh area, there are still a lot of factory waste and natural materials that have not been used optimally, such as pozzolan sand which is a type of natural material that contains silica and alumina compounds whose form is smooth so that it can be used as additional substances and replacement aggregate. In addition, fly ash which is waste...
originating from coal, and palm shells originating from solid waste that is removed from the palm kernel at the palm oil mill, can also be used as an alternative substitute for concrete. Therefore alternative economical materials such as coal fly ash, palm shell, and pozzolan sand are used as alternative substitute materials with lower production costs while maintaining the value of mechanical strength, even exceeding the strength of concrete using ordinary material.

The purpose of this study is to determine the mechanical properties of high quality concrete, namely split tensile strength, flexural tensile strength and absorption using alternative replacement materials, namely coal fly ash, palm shells, and pozzolan sand as additive substitutes, fine aggregates and coarse aggregates and the addition of nanomaterial iron ore fillers.

2. Literature Review

2.1. High Quality Concrete

According to Mulyono (2005), concrete criteria began to change along with the development of the times and progress of quality level that was achieved in accordance with the development of concrete technology. In the 1950s, concrete was categorized as having high quality if the compressive strength was 30 MPa, in 1960 - 1970 the criteria rose to 40 MPa. Currently concrete is said to be high quality concrete if its strength is above 55 MPa and 80 MPa as very high quality concrete, whereas 120 MPa can be categorized as ultrahigh quality concrete.

2.2. Additional Materials

2.2.1. Fly Ash Coal. In ASTM C.618 (ASTM, 1995: 304) it is explained that fly ash is defined as fine grains resulting from coal combustion residues or coal powder. Fly ash can be divided into two, namely normal fly ash produced from burning of anthracite coal or bituminous coal and class C fly ash produced from lignite or subbituminous coal. Class C fly ash may contain lime more than 10% by weight.

Fly ash is very well used for concrete mix because it has the ability to bind cement in the presence of water and its fine particle size, silica oxides contained by fly ash will react chemically with calcium hydroxide in the form of cement hydration and produce substances that have the binding ability. This is proven by research conducted by Syakuri and Haryadi (1997), Harison (2014), Borris (2012), Arifi (2017), dan Yerramala (2012).

2.2.2. Superplasticizer. Mulyono (2005) defines a superplasticizer as a chemical admixture that will dissolve lumps by coating cement paste so that cement can be spread evenly on the concrete mortar and will have an effect in increasing concrete workability to a considerable extent.

2.2.3. Palm Shells. Palm shells are solid waste that is removed from the palm kernel in the palm oil mill. At the palm oil mill, this waste is used as fuel in the boiler furnace because the palm shell contains activated carbon.

2.2.4. Pozzolan Sand. According to ASTM C.593-82, being viewed from the process of its formation, the pozzolan material can be divided into two types, namely natural pozzolan and artificial pozzolan. Based on the research of Jamal and Shannag (2000), it shows that the use of 15% natural pozzolan results in an increase in mechanical properties that are higher than without pozzolan.

2.2.5. Nanomaterial Iron Ores. Nano technology is the manufacture and use of materials at very small size that is in the realm of 1 to 100 nanometers (nm). The nanoscale is unique because there are no dense structures that can be reduced. Additionally, the mechanism of the biological and physical world takes place at 0.1 to 100 nm. The presence of nanosilica and nano CaCO3 in fly ash can reduce total capillary porosity and pore diameter, thereby reducing water permeability (Du Sen and Wu Junliang: 2019).

2.3. Split Tensile Strength
According to SNI 03-2491-2002, the value of the indirect tensile strength of a cylindrical concrete specimen obtained from the loading of the test specimen is placed horizontally parallel to the surface of the pressure test machine pressing table.

The magnitude of the tensile strength value above is obtained from the formula below.

\[
f_{tr} = \frac{2P}{\pi LD}
\]

Note;

\( f_{tr} \) : Concrete tensile strength (kg/cm\(^2\))
\( P \) : Maximum test load (split / crushed load) (kg)
\( L \) : Height / length of the cylinder (cm)
\( D \) : Cylinder diameter (cm)

The tensile strength of concrete in general has strengths ranging from 1/8 to 1/12 times the compressive strength of concrete. Tension stress that arises can be calculated using Equation 2.1 (Dipohusodo, 1994: 10).

2.4. Concrete Tensile Strength

Flexural tensile strength is the flexural tensile strength of concrete that arises in flexural testing of plain concrete blocks (without reinforcement). The flexural tensile strength testing aims to control the initial crack formation of concrete. According to Dipohusodo (1993) the magnitude of the bending stress can be found by the equation 2.2. That flexural tensile strength of concrete can be calculated as follows:

\[
f_r = \frac{PL}{bh^2}
\]

Note:

\( P \) = Maximum load (kg)
\( L \) = Span length (distance) between two support beams
\( b \) = Width of cross section beam
\( h \) = Height of cross section beam
2.5. Absorption

Concrete absorption is the entry of water from capillary cavity or pores found on the surface of concrete to the inner layer when the concrete is in contact with water. Absorption testing is carried out based on ASTM C 642 method, using cube-shaped specimens measuring 5 x 5 x 5 cm. The test is performed on 28 day old concrete to measure the absorption value of water in the standard age of concrete. According to Tjokrodimuljo (1996), water absorption capacity of a concrete can be measured by comparing the weight of oven-dried concrete and the weight of concrete in SSD (Saturated-Surface-Dried) condition after specified soaking time limit, which can be formulated into Formula 2.4 as follows.

\[ \% \text{ water absorption} = \frac{V_w - V_d}{V_d} \times 100\% \]

Note:

- \( V_w \) = Wet sample weight (gram)
- \( V_d \) = Dry sample weight (gram)

3. Research Method

3.1. Research Procedure

3.1.1. Mix Design. Mix design is intended to determine the composition or proportion of constituent materials. This step is required for the mixture proportion to meet technical as well as economical requirements. In this research, mix design is planned by comparing volume percentage of concrete components. Concrete is selected with characteristics of 70 MPa compressive strength and cement water factor (FAS) of 0.30. Viscocrete-10 superplasticizer is added 1.5% by weight of cement.

3.1.2. Test Specimen Planning. Test specimens are customized based on research need. Split tensile strength test utilizes cylindrical specimens with diameter of 15 cm and height of 30 cm; while flexural tensile strength test utilizes beam-shaped specimens measuring 15 x 15 x 60 cm, and absorption test utilizes cube-shaped specimens measuring 5 x 5 x 5 cm. Test specimens consist of: normal high quality concrete, high quality concrete with additive substitution, fine aggregate, coarse aggregate, and filler addition. Percentages of alternative materials are: coal fly ash 15%, palm shell ash 15%, pozzolan ash 10%, palm shell as fine aggregate substitution 20%, pozzolan sand 10%, palm shell as coarse aggregate substitution 40%, and nanomaterial filler of iron ore 6% by weight of cement. Test specimens planning can be seen in Table 1.

Table 1. Variation and Quantity of Specimen for Split Tensile Strength Test, Flexural Tensile Strength Test and High-Quality Concrete Absorption Test

| Num | Test Specimen Code | Substitution | Test Specimen | Total |
|-----|-------------------|--------------|---------------|-------|
|     |                   | Cement       | Fine Aggregate | Coarse Aggregate | 28 Day Old | 56 Day Old |   |
| 1   | BMT-N             | Without Substitute Material | 3 | 3 | 6 |
| 2   | BMT-FBPP          | Coal fly ash 15% | Pozzolan sand 10% | 3 | 3 | 6 |
| 3   | BMT-FBCS          | Coal fly ash 15% | Palm shell 20% | Palm shell 40% | 3 | 3 | 6 |
| 4   | BMT-ASPP          | Palm shell ash 15% | Pozzolan sand 10% | 3 | 3 | 6 |
5 BMT-ASCs Palm shell ash 15% Palm shell 20% 3 3 6

6 BMT-APPP Pozzolan ash 10% Pozzolan sand 10% 3 3 6

7 BMT-APCS Pozzolan ash 10% Palm shell 20% 3 3 6

Total 42

Note: Added to all specimens, iron ore nanomaterial fillers of 6% and superplasticizers 1.5% by weight of cement.

3.2. Split Tensile Strength Test of Concrete
Split tensile strength test is carried out by slowly putting horizontal load above a specimen until the test object is destroyed or cracked. Portable Compression Testing Machine Number Mic-10-1-12 is used to measure compressive strength.

![Figure 3. Split Tensile Strength Test](image)

3.3. Flexural Tensile Strength Test
For flexural components, the strength value is observed through cross-section design/analysis. Flexural strength is measured by testing plain concrete beam. The procedure can be seen in Figure 4 below.

![Figure 4. Flexural Tensile Strength Test](image)
3.4. Absorption Testing
Concrete absorption testing is performed on 28 and 56 day old specimens. One day before testing, the test specimens are removed from the soaking tub to dry. The specimens were then put into oven for 24 hours at 105 °C. After that, the oven-dry specimens are weighed and their dimensions are measured. Furthermore, the test materials are immersed in water.

4. Result and Discussion

4.1. Result

4.1.1. Split Tensile Strength Test Result

| Specimen Code | Test | Split Tensile Strength 28 Day Old (MPa) | Average Split Tensile Strength 28 Day Old (MPa) | Split Tensile Strength Test 56 Day Old (MPa) | Average Split Tensile Strength 56 Day Old (MPa) |
|---------------|------|----------------------------------------|-----------------------------------------------|---------------------------------------------|-----------------------------------------------|
| BMT – N       | 26   | 3.62                                   | 3.88                                           | 3.43                                        | 4.03                                          |
|               | 31   | 4.28                                   |                                                | 3.90                                        |                                               |
|               | 27   | 3.74                                   |                                                | 3.87                                        |                                               |
|               | 31   | 4.28                                   |                                                | 3.90                                        |                                               |
|               | 33   | 4.58                                   |                                                | 4.95                                        | 5.02                                          |
|               | 37   | 5.1                                    |                                                | 4.77                                        |                                               |
| BMT – FBPP    | 31   | 4.31                                   |                                                | 4.26                                        |                                               |
|               | 29   | 4.01                                   |                                                | 4.53                                        | 4.59                                          |
|               | 34   | 4.7                                    |                                                | 4.97                                        |                                               |
| BMT – FBCS    | 35   | 4.83                                   |                                                | 4.63                                        |                                               |
|               | 37   | 5.13                                   |                                                | 5.23                                        | 5.16                                          |
|               | 33   | 4.56                                   |                                                | 5.62                                        |                                               |
| BMT – ASPP    | 30   | 4.14                                   |                                                | 4.64                                        |                                               |
|               | 33   | 4.56                                   |                                                | 4.94                                        | 4.94                                          |
|               | 36   | 4.96                                   |                                                | 5.23                                        |                                               |
| BMT – ASCS    | 35   | 4.82                                   |                                                | 5.99                                        |                                               |
|               | 40   | 5.54                                   |                                                | 5.54                                        | 5.58                                          |
|               | 38   | 5.21                                   |                                                | 5.22                                        |                                               |
| BMT – APPP    | 34   | 4.72                                   |                                                | 4.98                                        |                                               |
|               | 35   | 4.86                                   |                                                | 5.51                                        | 5.33                                          |
|               | 38   | 5.25                                   |                                                | 5.50                                        |                                               |

4.1.2. Flexural Tensile Strength Test Result

| Specimen Code | Test | Flexural Tensile Strength 28 Day Old (MPa) | Average Flexural Tensile Strength 28 Day Old (MPa) | Flexural Tensile Strength Test 56 Day Old (MPa) | Average Flexural Tensile Strength Test 56 Day Old (MPa) |
|---------------|------|--------------------------------------------|-----------------------------------------------|---------------------------------------------|-----------------------------------------------|
| BMT – N       | 3,46 | 4.53                                       | 4.5                                            | 3.64                                        | 4.76                                          |
|               | 3,22 | 4.21                                       | 4.5                                            | 3.83                                        | 5.00                                          |
|               | 3,65 | 4.77                                       | 4.5                                            | 3.45                                        | 4.51                                          |
| BMT – FBPP    | 3,72 | 4.87                                       | 4.5                                            | 4.05                                        | 5.30                                          |
|               | 4,11 | 5.38                                       | 5.35                                           | 4.61                                        | 6.03                                          |
|               | 4,45 | 5.82                                       | 5.35                                           | 4.19                                        | 5.48                                          |
| BMT – FBCS    | 3,6  | 4.71                                       | 5.04                                           | 3.75                                        | 4.91                                          |
|               | 3,75 | 4.91                                       | 5.04                                           | 4.31                                        | 5.64                                          |


4.1.3. Absorption Test Result

| Test | Test Specimen Code | Weight of Concrete 28 Day Old (gram) | Absorption of Concrete 28 Day Old (%) | Weight of Concrete Aged 56 Day Old (gram) | Absorption of Concrete 56 Day Old (%) |
|------|--------------------|--------------------------------------|--------------------------------------|----------------------------------------|--------------------------------------|
|      | BMT – N            | 3.98                                 | 3.89                                 | 4.56                                   | 4.63                                 |
|      | BMT – FBPP         | 3.60                                 | 3.64                                 | 4.17                                   | 4.09                                 |
|      | BMT – FBCS         | 3.74                                 | 3.70                                 | 4.36                                   | 4.46                                 |
|      | BMT – ASPP         | 3.28                                 | 3.45                                 | 2.97                                   | 3.62                                 |
|      | BMT – ASCS         | 3.51                                 | 3.45                                 | 3.81                                   | 3.79                                 |
|      | BMT – APPP         | 3.85                                 | 3.99                                 | 4.13                                   | 4.31                                 |
|      | BMT – APCS         | 3.98                                 | 3.99                                 | 4.22                                   | 4.46                                 |

5. Conclusion

1. Split tensile strength and flexural tensile strength of high quality hybrid concrete are greater than normal high quality concrete.
2. Maximum split tensile strength is found in high quality hybrid concrete with variations of BMT-APPP (pozzolan ash + fine pozzolan sand aggregate + coarse palm shell aggregate + iron ore nanomaterial filler) of 5.19 MPa at 28 day old specimen and 5.58 MPa at 56 day old specimen.
3. Maximum flexural tensile strength is visible in high quality hybrid concrete with variations of BMT-APPP (pozzolan ash + fine pozzolan sand aggregate + coarse palm shells aggregate + iron ore nanomaterial fillers) of 5.73 MPa at 28 day old specimen and 6.11 MPa at 56 day old specimen.
4. Maximum absorption of 4.63% can be seen in normal high quality concrete of 56 day old.
5. The best high quality concrete found in this study is the variation of BMT-APPP.
6. Substitution of cement, fine aggregate, coarse aggregate and the addition of iron ore nanomaterial fillers can be used in high quality concrete to produce higher tensile strength.
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