The mechanical properties of limestone as an aggregate on high strength concrete

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Abstract. The construction of multi-stories buildings is increasing rapidly. In concrete construction, various studies and innovations have been carried out in order to obtain high strength concrete. The use of limestone either as a substitute for fine aggregate, as a substitute for coarse aggregate or as a substitute for fine aggregate and even coarse aggregate in a concrete mixture is still lacking. In South Sulawesi, large quantities of limestone are found in several regencies. Enrekang Regency is one with considerable limestone potential which is about 74.75 km² or an estimated geological of 3.7 billion cubic meters. Most limestone is made into split stones that can be used as construction materials. Limestone can be processed into split or powder which can be used as a replacement for sand in concrete mixture. The results of the concrete at 28 days with a mixture of natural sand as fine aggregate and limestone split as coarse aggregate, w/c ratio of 0.20 produced a value of $f'c = 59.26$ MPa, $ft = 4.51$ MPa (0.61$\sqrt{f'c}$), and $fr = 7.18$ MPa (0.93$\sqrt{f'c}$). The average modulus of elasticity at 28 days with a mixture of limestone powder as fine aggregate and limestone split as coarse aggregate produced a value of $E_c = 46960.25$ MPa (6325 $\sqrt{f'c}$) with Poisson’s ratio $\nu = 0.3847$.

1. Introduction

The construction of multi-stories buildings is increasing rapidly. Various kinds of construction have been used such as concrete construction, steel construction or a combination of both (composite). In concrete construction, various studies and innovations have been carried out in order to obtain high strength concrete. Concrete is a material made from mixing sand, gravel, cement and water with or without the use of additional mixtures. High strength concrete has high compressive strength at 28 days. The definition of high strength concrete is concrete with compressive strength above 60 MPa [1]. Reference [2] stated that high strength concrete is concrete with a compressive strength of more than 41.4 MPa.

There are several factors that need to be considered to produce high strength concrete, such as: water cement ratio, fine aggregate quality, coarse aggregate quality and the use of additional mixture (chemical and mineral). Both the quality of the constituent materials and admixture are required for high strength concrete. The optimum level of use of superplasticizer (admixtue) and silicafume (additive) to obtain maximum compressive strength in high quality concrete mix is 2% superplasticizer and 10% silicafume, as stated in [3] and [4]. Concrete constituent material which consists mainly of gravel as coarse aggregate and natural sand as fine aggregate is commonly found on
construction site. The use of limestone either as a substitute for fine aggregate, as a substitute for coarse aggregate or as a substitute for fine aggregate and even coarse aggregate in a concrete mixture is still lacking.

The use of limestone in concrete might be possibly utilized due to its great potential as material resources commonly found in several provinces in Indonesia. In South Sulawesi, large quantities of limestone are found in several regencies. Enrekang Regency is one with considerable limestone potential which is about 74.75 km² or an estimated geological of 3.7 billion cubic meters. Limestone is a sedimentary rock composed primarily of calcium carbonate (CaCO₃) minerals in the form of calcite minerals. It can be formed in several ways, such as organically, mechanically or chemically. Limestone is a rock with a very large diversity of uses.

Most limestone is made into split stones that can be used as construction materials such as: foundations, roadways and railways as well as aggregates in concrete [5]. Limestone is one of the most widely used compared to other types of rocks because of its porosity, strong and dense nature. This physical property allows limestone to stand firm despite undergoing an abrasion process. Although limestone is not as hard as silicate composition, but limestone is easier to mine and does not quickly cause wear and tear on mining equipment or stone breaking equipment. Limestone can be processed into split or powder which can be used as a replacement for sand in concrete mixture.

The addition of limestone powder originated from Manyaran, Wonogiri as a replacement of cement (up to 15%), with a water cement ratio of 0.4 showed a tendency to increase the compressive strength of concrete by 0.95% [6]. Limestone research in Sampang, Madura, shows that the compressive strength is higher as the increasing percentage of limestone as a substitute for coarse aggregate [7]. Therefore, the study is conducted to research "The Mechanical Properties of Limestone as An Aggregate on High Strength Concrete".

2. Methodology

This research was conducted at the Laboratory of Materials and Structure of the Civil Engineering Department, Polytechnic of Ujung Pandang and at the Eco Material Laboratory, Faculty of Engineering, Hasanuddin University, Gowa. Natural sand as fine aggregate, originating from the Jeneberang River, Sunggu Minasa, Gowa Regency, South Sulawesi. Limestone as fine aggregate and coarse aggregate, originated from Enrekang Regency, South Sulawesi. PCC (Portland Composite Cement) cement type I is used in this research. Additive material, the "Sikament LN" superplasticizer is used.

The aggregate variable mixture consists of a mixture of fine aggregate from natural sand and coarse aggregate from limestone; a mixture of fine aggregate from limestone and coarse aggregate from limestone. Water cement ratio (w/c ratio) is 0.20, 0.25 and 0.30. The testing period is 3 days, 7 days, 28 days and 56 days. Concrete mechanical properties test includes compressive strength test, split tensile strength test, flexural strength test, modulus of elasticity and Poisson’s ratio. The number of samples for each variable taken as many as 3 pieces. The testing procedure refers to the American Society for Testing Materials ASTM C192 / C192M in 2007. The testing procedure refers to SNI 1974 in 2011, SNI 4431 in 2011 and SNI 2491 in 2014.

| Aggregate                | w/c | Time (days)  | Each sample | Total samples |
|--------------------------|-----|--------------|-------------|---------------|
| Natural sand and limestone | 0.20   | 3, 7, 28 and 56 | 3           | 12            |
|                          | 0.25   | 3, 7, 28 and 56 | 3           | 12            |
|                          | 0.30   | 3, 7, 28 and 56 | 3           | 12            |
| Limestone powder and      | 0.20   | 3, 7, 28 and 56 | 3           | 12            |
|                          | 0.25   | 3, 7, 28 and 56 | 3           | 12            |
limestone split 0.30 3, 7, 28 and 56 3 12

Table 2. The sample of split tensile strength test

| Aggregate               | w/c | Time (days)     | Each sample | Total samples |
|-------------------------|-----|-----------------|-------------|---------------|
| Natural sand and limestone | 0.20 | 3, 7, 28 and 56 | 3           | 12            |
|                         | 0.25 | 3, 7, 28 and 56 | 3           | 12            |
|                         | 0.30 | 3, 7, 28 and 56 | 3           | 12            |
| Limestone powder and limestone split | 0.20 | 3, 7, 28 and 56 | 3           | 12            |
|                         | 0.25 | 3, 7, 28 and 56 | 3           | 12            |
|                         | 0.30 | 3, 7, 28 and 56 | 3           | 12            |

Table 3. The sample of flexural strength test

| Aggregate               | w/c | Time (days)     | Each sample | Total samples |
|-------------------------|-----|-----------------|-------------|---------------|
| Natural sand and limestone | 0.20 | 3, 7, 28 and 56 | 3           | 12            |
|                         | 0.25 | 3, 7, 28 and 56 | 3           | 12            |
|                         | 0.30 | 3, 7, 28 and 56 | 3           | 12            |
| Limestone powder and limestone split | 0.20 | 3, 7, 28 and 56 | 3           | 12            |
|                         | 0.25 | 3, 7, 28 and 56 | 3           | 12            |
|                         | 0.30 | 3, 7, 28 and 56 | 3           | 12            |

3. Result and Discussion
The characteristics results of natural sand as fine aggregate, limestone powder as fine aggregate and limestone split as coarse aggregate can be seen in Table 4, Table 5 and Table 6. It can be seen that natural sand and limestone powder with mud content of 4.97% and 4.41% respectively, are almost exceed the maximum threshold required.

Table 4. Specifications and characteristics of natural sand as fine aggregate

| No. | Type           | Interval limit | Test result | Note |
|-----|----------------|----------------|-------------|------|
| 1.  | Mud content    | 0.2% – 5%      | 4.97 %      | Ok   |
| 2.  | Organic content| < No.3         | < 2         | Ok   |
| 3.  | Water content  | 3%-5%          | 10.89 %     | High |
| 4.  | Volume weight  | 1.4-1.90 (kg/lt) | 1.45 kg/lt | Ok   |
| 5.  | Absorption     | 0.20%-2.00%    | 4.578 %     | High |
| 6.  | SSD specific gravity | 1.60-3.20 | 2.451 | Ok |
| 7.  | Fineness modulus | 2.20-3.10  | 3.47 | High |

Table 5. Specifications and characteristics of limestone powder as fine aggregate

| No. | Type           | Interval limit | Test result | Note |
|-----|----------------|----------------|-------------|------|
| 1.  | Mud content    | 0.2% – 5%      | 4.41 %      | Ok   |
2. Organic content  <No.3  < 2  Ok
3. Water content  3%-5%  0.349 %  Low
4. Volume weight  1.4-1.90 (kg/ltr)  1.77 kg/ltr  Ok
5. Absorption  0.20%-2.00%  0.674 %  Ok
6. SSD specific gravity  1.60-3.20  2.606  Ok
7. Fineness modulus  2.20-3.10  4.03  High

Table 6. Specifications and characteristics of limestone split as coarse aggregate

| No. | Type                      | Interval limit | Test result | Note |
|-----|---------------------------|----------------|-------------|------|
| 1   | Mud content               | 0.2% – 1.0%    | 1.19 %      | High |
| 2   | Wear capacity             | 15%-50%        | 20.28       | Ok   |
| 3   | Water content             | 0.5%-2.0%      | 0.072 %     | Low  |
| 4   | Volume weight             | 1.4-1.90 (kg/liter) | 1.525 kg/litr | Ok |
| 5   | Absorption                | 0.20%-4.00 %   | 1.22 %      | Ok   |
| 6   | SSD specific gravity      | 1.60-3.20      | 2.631       | Ok   |

Figure 1. Gradation of natural sand

Figure 2. Gradation of limestone powder

The analysis results of both natural sand and limestone powder as fine aggregate are shown in Figure 1 and Figure 2 respectively. It can be seen that natural sand is in gradation zone II while limestone powder is in the gradation zone I. The results of the mixture design of high strength concrete with the compressive strength of $f'_c = 50$ MPa can be seen in Table 7 and Table 8 respectively.
Relationship between the compressive strength of concrete vs time with various factors of w/c ratio is shown in Figure 3 and Figure 4. It can be seen that the combination of natural sand as fine aggregate and limestone split as coarse aggregate at 28 days gives a higher average compressive strength of $f'_c = 59.26$ MPa compared to the combination of limestone powder as fine aggregate and limestone split as coarse aggregate with $f'_c = 55.13$ MPa.

A low value of w/c ratio 0.20 gives a concrete compressive strength test results higher than the w/c ratio 0.25 and 0.30. While the average slump test already fulfilled the expected slump test value of between 25 mm to 150 mm. The results of compressive strength test for various specimens show that the average collapse is marked by the splitting of the test pieces into longitudinal pieces. Failure type like this is typically found for high compressive strength concrete due to the superior of internal friction in the concrete mixture.

Table 7. The composition of natural sand as fine aggregate and limestone split as coarse aggregate

| No. | Material (Kg)            | w/c ratio 0.20 | w/c ratio 0.25 | w/c ratio 0.30 |
|-----|--------------------------|----------------|----------------|----------------|
| 1   | Cement 950.00            | 760.00         | 633.33         |
| 2   | Natural sand 404.84      | 469.47         | 512.57         |
| 3   | Limestone split 799.91   | 927.63         | 1012.77        |
| 4   | Water 163.85             | 163.78         | 163.73         |
| 5   | Sikament LN (1.20 %)     | 11.40          | 9.12           | 7.60           |
|     | Total : 2330             | 2330           | 2330           |

Table 8. The composition of limestone powder as fine aggregate and limestone split as coarse aggregate

| No. | Material (Kg)           | w/c ratio 0.20 | w/c ratio 0.25 | w/c ratio 0.30 |
|-----|-------------------------|----------------|----------------|----------------|
| 1   | Cement 950.00           | 760.00         | 633.33         |
| 2   | Limestone powder 430.85 | 497.13         | 541.32         |
| 3   | Limestone split 793.53  | 915.62         | 997.00         |
| 4   | Water 189.22            | 193.13         | 195.74         |
| 5   | Sikament LN (1.20 %)    | 11.40          | 9.12           | 7.60           |
|     | Total : 2375             | 2375           | 2375           |
Figure 3. Compressive strength for natural sand as fine aggregate and limestone split as coarse aggregate

Figure 4. Compressive strength for limestone powder as fine aggregate and limestone split as coarse aggregate

Table 9. Relationship of split tensile strength with concrete compressive strength

| Mixture type | w/c ratio | $f_t$ (MPa) | $f'_c$ (MPa) | $f_t \approx 0.56 \sqrt{f'_c}$ |
|--------------|-----------|-------------|--------------|--------------------------------|
| A            | 0.20      | 4.03        | 59.26        | 0.52 $\sqrt{f'_c}$          |
|              | 0.25      | 3.75        | 53.90        | 0.51 $\sqrt{f'_c}$          |
|              | 0.30      | 3.54        | 45.70        | 0.52 $\sqrt{f'_c}$          |
| B            | 0.20      | 4.51        | 55.13        | 0.61 $\sqrt{f'_c}$          |
|              | 0.25      | 4.20        | 45.67        | 0.62 $\sqrt{f'_c}$          |
|              | 0.30      | 4.01        | 45.27        | 0.61 $\sqrt{f'_c}$          |

A: natural sand as fine aggregate and limestone split as coarse aggregate  
B: limestone powder as fine aggregate and limestone split as coarse aggregate

Table 10. Relationship of flexural strength with concrete compressive strength

| Mixture type | w/c ratio | $f_r$ (MPa) | $f'_c$ (MPa) | $f_r \approx 0.62 \sqrt{f'_c}$ |
|--------------|-----------|-------------|--------------|--------------------------------|
| A            | 0.20      | 7.18        | 59.26        | 0.93                           |
|              | 0.25      | 5.97        | 53.90        | 0.81                           |
Table 11. Average modulus of elasticity and Poisson’s ratio

| Mixture type | w/c ratio | $f'_c$ (MPa) | $E_{c1}$ (MPa) | Coeff $E_{c2}$ | $\nu$ |
|--------------|-----------|--------------|----------------|----------------|------|
| A            | 0.20      | 59.26        | 29665.47       | 3854 $\sqrt{f'_c}$ | 0.2344 |
|              | 0.25      | 53.90        | 33295.11       | 4535 $\sqrt{f'_c}$ | 0.2233 |
|              | 0.30      | 45.70        | 30671.92       | 4537 $\sqrt{f'_c}$ | 0.1823 |
| B            | 0.20      | 55.13        | 46960.25       | 6325 $\sqrt{f'_c}$ | 0.3847 |
|              | 0.25      | 45.67        | 34487.35       | 5103 $\sqrt{f'_c}$ | 0.2285 |
|              | 0.30      | 45.27        | 35751.25       | 5313 $\sqrt{f'_c}$ | 0.2511 |

A: natural sand as fine aggregate and limestone split as coarse aggregate
B: limestone powder as fine aggregate and limestone split as coarse aggregate

The average relationship between the split tensile strength of concrete with its compressive strength based on SNI 2847: 2013 [8] for various mixtures and w/c ratio can be expressed as the equation of $f_t = 0.56 \sqrt{f'_c}$. Its calculation is shown in Table 9. The average relationship between the flexural strength of the concrete with its compressive strength based on SNI 2847: 2013 for various mixtures and w/c ratio can be expressed as the equation of $f_r = 0.62 \sqrt{f'_c}$. Its calculation is shown in Table 10. Table 11 shows that the compressive strength of a mixture of natural sand as fine aggregate and limestone split as coarse aggregate is quite high but also gives a large enough strain so that the modulus of elasticity becomes slightly smaller from the other mixture. Modulus of elasticity equation obtained can be expressed as $E_c = 3854 \sqrt{f'_c}$ (MPa) while $E_c = 4700\sqrt{f'_c}$ (MPa) for normal concrete as described in SNI 2847: 2013.

4. Conclusion
The results of the concrete at 28 days with a mixture of natural sand as fine aggregate and limestone split as coarse aggregate, w/c ratio of 0.20 produced a value of $f'_c = 59.26$ MPa. $f_t = 4.51$ MPa ($0.61\sqrt{f'_c}$), and $f_r = 7.18$ MPa ($0.93\sqrt{f'_c}$). The average modulus of elasticity at 28 days with a mixture of limestone powder as fine aggregate and limestone split as coarse aggregate produced a value of $E_c =$
46960.25 MPa (6325 $\sqrt{f'_c}$) with Poisson’s ratio $\nu = 0.3847$.

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