The effect of polypropylene fiber addition to mechanical properties of concrete

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Abstract. Concrete is one of the building construction materials that has a high compressive strength, but it has lower tensile strength. The addition of fibers to concrete is expected to improve its mechanical properties. In this study, the concrete was added with Polypropylene (PP) fiber with a length of 12 mm. The compressive strength of concrete specimens was 20 MPa with the variety of fiber used was 0.5 kg/m³; 1 kg/m³; and 1.5 kg/m³. The test were conducted on 36 specimens in the form of cylinders and cubes. The tests were compressive strength, split tensile strength and water absorption at the age of 28 days. The highest value of the compressive strength of the fiber concrete was the amount of Polypropylene fiber 1 kg/m³, namely 2.92 MPa, increase of 6.92% of the compressive strength of concrete without additional fiber. The highest value for the split tensile strength in the amount of Polypropylene fiber 1 kg / m³ was 2.34 MPa or an increase of 21% from the tensile strength value of concrete without additional fiber. Meanwhile, the lowest water absorption capacity of concrete is the addition of 1.5 kg/m³ of fiber, which is 2.366% or has decreased by 64% from the concrete without fiber.

1. Introduction
Concrete is a composite material that very effective as the main structural material in building construction, because it has high compressive strength. The compressive strength of concrete tends to be greater than the split tensile strength value of concrete, the tensile strength value of concrete ranges from only 9% -15% of the compressive strength of concrete [1]. The weakness of the concrete in resisting the tensile force can be seen from the appearance of hair cracks due to loading on the structural concrete. Cracks usually appear on concrete surfaces that are subjected to tensile or bending loads which result in concrete destruction [2].

Various concrete innovations are made with the concept of improving the weaknesses of concrete properties, by increasing the tensile strength, one of which is the addition of fiber to the concrete. The basic concept is to reinforce concrete with fibers that are randomly dispersed into the concrete mix, so as to prevent premature cracking due to loading [3], it can be illustrated in Figure 1. Polypropylene (PP) fiber is a plastic material that is often used in life. Daily include snack wrappers, straws, raffia ropes, rice sacks, etc. made from plastic. Polypropylene is a water resistant fiber so it cannot absorb water [4]. This fiber is a fiber that has a low density and does not absorb water, so that this fiber does not significantly change the physical properties of concrete but can change the mechanical properties of concrete [5]. Polypropylene fibers are macroscopic in size and flexible in nature so that they have a tensile strength of up to 310-760 MPa with a fiber elongation of up to 15% and have a waterproof surface so they cannot absorb water [4].
The effect of adding polypropylene fibers to the mechanical behavior of normal concrete, namely an increase in split tensile strength of about 2.25% to normal concrete [6]. The results of the split tensile test of cylindrical specimens with the addition of Polypropylene fibers have an increase in split tensile strength at a fiber quantity of 0.9 kg / m$^3$ with concrete FAS of 0.55, namely 2.6 MPa with an increase of 3.17% from normal concrete. The optimum tensile strength value for concrete with a fiber content of 0.9 kg / m$^3$ with FAS of 0.35 is 5.76% [7]. That the behavior of lightweight foam concrete after adding polypropylene fibers at a level of 0.75% of volume weight resulted in an increase in compressive strength, split tensile strength, and modulus of elasticity, respectively, of 27.93%; 60.38%; and 44.31% compared to lightweight foam concrete without fiber [8]. Polypropylene fibrous concrete has a higher tensile strength value than normal concrete without fiber, namely the addition of fiber, respectively 1.0 kg / m$^3$, 0.4 kg / m$^3$, 0.6 kg / m$^3$ and 0.8 kg / m$^3$ increased by 40.22%, 30.43%. 33.70% and 35.87% [9]. The addition of PP fiber by 1.5% of the amount of cement can increase the compressive strength by 16% and split tensile strength by 17% at 28 days of concrete compared to the control sample [10]. The high tensile and pull-out strength of PP fibers even reduce the early plastic shrinkage cracking by enhancing the tensile capacity of fresh concrete to resist the tensile stresses caused by the typical volume changes. The fibers also distribute these tensile stresses more evenly throughout the concrete [11]. Sohaib et al. [12] revealed that significant improvement of concrete was observed in ultimate compressive strength after 7 and 28 days. The optimum percentage of Polypropylene fiber was obtained to be 1.5% of cement by volume. The addition of small amount of polypropylene improved the mechanical properties of concrete. Sharan and Lal [13] concluded the strength increase of 17% polypropylene fiber reinforced concrete. Strength enhancement in split tensile strength of 22%, flexural strength of 24% and modulus of elasticity of 11% were also reached. It was observed that 1.5% fiber in concrete yielded maximum strength. Different finding was obtained by Ahmed and Daoud [14]. The workability of concrete decreased with the addition of polypropylene fibres. It was also showed a reduction in modulus of elasticity occurred after 28 days, compared to the control. The increase in flexural strength and splitting tensile strength were observed.

The aim of this study was to determine the relationship between the additions of polypropylene fibers to the performance of concrete. The concrete performance observed was compressive strength, tensile strength, and water absorption.

2. Material and Methods
Concrete consists of several materials that support each other and must base on standards and quality in accordance with the mix design. The materials used in the concrete fiber mixture are cement, gravel, sand, water and polypropylene fibers, as shown in Figure 2. The research was conducted at the Civil Engineering Laboratory of the Universitas Negeri Semarang with test materials included analysis of aggregate grains, specific gravity and sludge content tests for concrete planning (mix design) refers to SNI-7656-2012 [15].
Figure 2. Polypropylene fiber concrete mixture

The concrete used is f\(c\) 20 MPa with the addition of Polypropylene fibers 0 kg/m\(^3\) (control), 0.5 kg/m\(^3\), 1 kg/m\(^3\), and 1.5 kg/m\(^3\). The fiber (PP) used is 12 mm in size. The concrete specimen is cylindrical with a diameter of 15 cm and a height of 30 cm for use the split tensile strength test, while for testing the compressive strength and water absorption capacity of concrete cubes with a size of 15 x 15 x 15 cm. Total amount of test specimens is 24, where for each test treatment were 3 pieces.

2.1. Research procedure
The test implementation steps:
- The first is testing of aggregate properties for sand and gravel.
- after that create a mix design of fiber concrete with addition polypropylene fiber 0.5 kg/ m\(^3\); 1 kg/m\(^3\), dan 1.5 kg/m\(^3\)
- Make concrete according to the mix design that has been made by concrete mixer
- The concrete is filled in cylindrical and cube mold. After 24 hour of age the mold is removed, and then soaked for 28 days
- The concrete is oven dried and some sun dried
- The concrete is ready for testing
- the concrete is tested by Universal Testing Machine
- The data are analyzed.

Figure 3. The steps of research

3. Result and Discuss

3.1. Material Properties test
Material properties tests include analysis of aggregate grains, density and absorption test and sludge content test, and gravel hardness test. The concrete materials tested are sand and gravel, test results are as shown in Table 1 and Table 2.

Table 1. Result of sand properties test
The aggregate sludge content exceeds the maximum limit referred to in SNI, which is 5% for fine aggregate, while the results show the value of sludge content of 6.95%, while the sludge content for coarse aggregate has a maximum limit of 1% and the test results show the result of 1.03%. To remove excess sludge in the aggregate, a special treatment is carried out by washing the aggregate and then drying it in the sun until the condition is Saturated Surface Dry.

3.2. Compressive Strength

Testing the compressive strength of concrete, the calculation of the compressive strength of concrete using the formula for the compressive strength of concrete is based on the provisions of SNI-1974–2011. The results of the concrete compressive strength test and the increase in compressive strength diagram can be seen in Table 3 and Figure 4.

| No | PP fiber (kg/m³) | Max load (kg) | Compressive strength (kg/cm²) (MPa) | average (MPa) |
|----|------------------|---------------|------------------------------------|--------------|
| 1  | 0                | 62434         | 277.48 23.03 22.37                 |              |
|    |                  | 60256         | 267.80 22.23                       |              |
|    |                  | 59223         | 263.21 21.85                       |              |
| 2  | 0.5 kg/m³       | 60220         | 267.64 22.21 22.85                 |              |
|    |                  | 61740         | 274.40 22.78                       |              |
|    |                  | 63854         | 283.80 23.56                       |              |
| 3  | 1 kg/m³         | 65742         | 292.19 24.25 23.92                 |              |
|    |                  | 64095         | 284.87 23.64                       |              |
|    |                  | 64700         | 287.56 23.87                       |              |
| 4  | 1.5 kg/m³       | 59663         | 265.17 22.01 22.34                 |              |
|    |                  | 60685         | 269.71 22.39                       |              |
|    |                  | 61304         | 272.46 22.61                       |              |
From Table 3 and Figure 4, it can be seen that the use of fiber in concrete can affect the compressive strength of concrete. The compressive strength of the specimen continues to increase along with the increase in polypropylene fiber content, due to the working mechanism of the fiber together with the concrete paste to form a composite matrix. However, to a certain extent the compressive strength has decreased. This could be because the fiber reinforcement in the concrete occurs naturally, but because the random distribution of fibers is not in the direction of the load received, so it can prevent the bonding between the materials. The addition of polypropylene fibers of 0.5 kg/m³ and 1 kg/m³ obtained an increase in the average compressive strength of 22.85 MPa and 23.92 MPa with increases of 2.14% and 6.92% respectively of the control concrete without fiber 22.37 MPa. However, with the addition of 1.5 kg/m³ of fiber, the compressive strength has decreased to 22.34 MPa. The maximum increase in the compressive strength of concrete occurred in the specimen containing fiber content of 1 kg/m³ with an increase of 6.92% from the concrete without polypropylene fibers. While the smallest increase in compressive strength occurred in the addition of polypropylene fiber content of 1.5 kg/m³, namely 0.58% of the concrete without polypropylene fibers. However, the use of polypropylene fibers as an added material to the concrete mixture is still acceptable, this is because the resulting compressive strength still meets the requirements for structural concrete greater than or equal to 20 MPa.

3.3. Split Tensile Strength
The results of the average split tensile strength test can be seen in Table 4 and Figure 6. The specimen used is a cylinder with a diameter of 15 cm and a height of 30 cm.

| No | Fiber PP (kg/m³) | Max load (kg) | Split tensile strength (kgf/cm²) | average (MPa) |
|----|-----------------|---------------|---------------------------------|---------------|
| 1  | 0               | 13465         | 20.63                           | 1.91          | 2.00          |
|    |                 | 14573         |                                 |               |               |
|    |                 | 14383         |                                 |               |               |
| 2  | 0.5             | 16140         | 22.85                           | 2.28          | 2.34          |
|    |                 | 15997         |                                 |               |               |
|    |                 | 17432         |                                 |               |               |
| 3  | 1               | 18308         | 25.91                           | 2.59          | 2.42          |
|    |                 | 16724         |                                 |               |               |
|    |                 | 16309         |                                 |               |               |
| 4  | 1.5             | 16223         | 22.96                           | 2.30          | 2.19          |
|    |                 | 14945         |                                 |               |               |

Figure 4. Compressive strength of polypropylene fiber concrete
In Figure 5, the split tensile strength of concrete without the addition of Polypropylene fibers is 2.0 MPa and continues to increase along with the addition of fiber as much as 0.5 kg/m³ and 1 kg/m³, namely 2.34 MPa and 2.42 MPa. The maximum increase occurred for the test object with fiber 1 kg/m³, namely 2.42 MPa. In the specimen with the addition of 1.5 kg/m³ of fiber, the split tensile strength has decreased to 2.19 MPa. The percentage increase in the tensile strength of concrete reached 21% of the tensile strength of concrete without the addition of polypropylene fibers. The decrease in the tensile strength of the concrete is 9.7% of the value of the highest tensile strength of concrete. The decrease in the tensile strength of the concrete is caused by clumping of the polypropylene fibers when mixing the concrete which causes the adhesion between the cement paste and the aggregate to decrease because the tensile strength of the concrete is greatly influenced by the adhesion between the cement paste and coarse aggregate.

### 3.4. Water Absorption

The results of the average concrete water absorption test can be seen in Table 5 and Figure 6.

| Polypropylene fiber (kg/m³) | Surface dry weight kg | dry weight kg | Water absorption % | Average % |
|----------------------------|-----------------------|---------------|--------------------|-----------|
| 0                          | 8.40                  | 7.89          | 6.464              | 6.593     |
|                            | 8.37                  | 7.83          | 6.897              |           |
|                            | 8.29                  | 7.79          | 6.418              |           |
|                            | 8.38                  | 7.92          | 5.808              |           |
| 0.5                        | 8.13                  | 7.66          | 6.136              | 6.155     |
|                            | 8.33                  | 7.82          | 6.522              |           |
|                            | 8.18                  | 7.96          | 2.764              |           |
| 1                          | 8.02                  | 7.82          | 2.558              | 2.488     |
|                            | 8.10                  | 7.93          | 2.144              |           |
|                            | 7.81                  | 7.65          | 2.092              |           |
| 1.5                        | 8.01                  | 7.80          | 2.692              | 2.366     |
|                            | 7.96                  | 7.78          | 2.314              |           |
The graph shows the effect of using Polypropylene fibers on the water absorption capacity of concrete which decreases with the increase in the number of fibers in the concrete. The highest water absorption value was in the test object without the addition of Polypropylene fiber, namely 6.593%, while the addition of fiber of 1.5 kg / m$^3$ obtained a minimum water absorption capacity of 2.366%. The decrease in the water absorption capacity of concrete occurs due to the nature of the Polypropylene type synthetic fiber which does not absorb water, thus making the absorption smaller

4. Conclusion

Polypropylene fibers can be used for concrete mixes because increase its mechanical properties. From the test results, it was found that the compressive strength and split tensile strength of the concrete increased by addition of polypropylene fiber 1 kg/m$^3$. In the water absorption test, the addition of fiber is proven to reduce water absorption because the nature of polypropylene fiber which are hydrophobic (do not absorb water).

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