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Theoretical and Experimental Analysis of Concrete Stress-Strain with Artificial Coarse Aggregates and Steel Fibers

Meity Wulandari[1]

[1]*Faculty of Engineering, Universitas Negeri Surabaya.*
Email : [1]meitywulandari@unesa.ac.id.

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ABSTRACT

Artificial coarse aggregates is an innovation to replace natural coarse aggregate. In this study, the material used for the preparation of coarse aggregate is industrial waste, namely Expanded Polystyrene (EPS). The purpose of using this s in addition to knowing the magnitude of the compressive strength, it is also necessary to know the amount of strain that occurs when the concrete receives a load. In addition to improving the performance of compressive strength, steel fibers are also added to the concrete mixture. The method used in this research is experimental and analyzed with a mathematical model to determine the theoretical modeling of the stress-strain curve. The experimental test results show that the use of steel fibers can increase the compressive strength of normal concrete while the effect of this artificial coarse aggregates can increase the strain value by 39% of normal concrete. The results of experimental and theoretical comparisons of mixture composition which are considered to be closest to the stress-strain curve of normal concrete are concrete with a mixture of 15% artificial coarse aggregates and concrete with a mixture of 15% artificial coarse aggregates and 0,75% steel fibers.

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1. Introduction

Coarse aggregate is a granular material that is used as a constituent of concrete [1]. The use of coarse aggregate greatly affects the properties of concrete such as the compressive strength and specific gravity of concrete. Coarse aggregates commonly used are gravel or crushed stone. The use of crushed stone is currently still less efficient for the specific gravity of concrete [2]. As technology develops, many innovations have been developed, namely replacing gravel or crushed stone with artificial aggregates [3]. Artificial aggregates can be formed according to the characteristics of coarse aggregates in general. The main constituent material of the artificial aggregate will also affect the weight of the aggregate [4]. In this study, the main material used as the main constituent in the manufacture of artificial coarse aggregates is Expanded Polystyrene (EPS). EPS is very easy to obtain because it is one of the wastes from both small and large industries. The use of EPS is not only useful as a material for making artificial aggregates but is also beneficial for the environment which has a negative impact on the existence of this EPS waste. To reduce this negative impact, it is necessary to conduct research related to the effect of EPS on concrete mixtures [5].

EPS is widely used as a substitute for aggregate without changing the original form of the EPS. EPS can be melted down and re-dried with several chemical liquids, one of which is acetone. Physical changes from the initially soft EPS can become harder after experiencing the mixing process with Acetone. Changes in these characteristics of course need to be known how much influence it has on the stress and strain values of concrete when used as a substitute for natural coarse aggregate. Changes in behavior when the concrete receives a load of course also need to be analyzed theoretically.

The method used in this research is experimental and theoretical analysis with a mathematical model. The use of EPS in concrete mixtures has been widely used in several studies both as a substitute for coarse aggregate and fine aggregate. However, its effect on compressive strength is not very significant and has not reached the standard for compressive strength of structural concrete [6]. Concrete with artificial coarse and fine aggregates from plastic materials is able to produce lightweight concrete of 1800 kg/m^3 and has a compressive strength of 20 MPa at 28 days [4]. One of the studies related to the use of EPS is to make the specific gravity of concrete lighter because it is able to reduce 42,8% of the volume of concrete [7]. To increase the compressive strength of concrete in this study, an added material in the form of hooked end type steel fibers was used because based on the results of the study showed that the compressive strength of concrete increased when steel fibers was added [8][9]. The addition of steel fibers to the concrete mixture from several studies can increase the compressive strength of concrete [10][11]. The use of steel fibers volume as much as 1% in LWAC can increase the compressive strength by up to 5-10% [12]. In addition, the addition of hooked end steel fibers with a ratio (*l/d*) of 65/35 was able to increase the compressive strength of concrete by 10,81% from normal concrete [13]. Apart from knowing the stress and strain values that occur from the experimental results, it is also necessary to know the mathematical model.

Modeling of the concrete stress-strain curve is needed to determine the behavior of the concrete material when carrying a working load [14]. The mathematical characteristics of the stress-strain curve of steel fibers concrete are similar to those of normal concrete and can be used to calculate the stress-strain curve by using the appropriate parameters [15]. This study aims to determine the compressive stress-strain of concrete with artificial coarse aggregates and steel fibers theoretically and experimentally so that it can be compared with normal concrete. From the results of this research, it will be known the composition that is closest to normal concrete based on theoretical analysis of the stress-strain values.

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2. Research Method

2.1 Material

The materials used in this research include:

a. Fine Aggregates

Fine aggregates used in the form of natural sand with a type weight of 2,66 gr/cm^3 which refers to the standard ASTM C 128 [16].

Figure 1. Fine Aggregates
Source: Research data

b. Coarse Aggregates

Coarse aggregate used in the form of split stone size 10-20 mm with a type weight of 2,62 gr/cm^3 which refers to the standard ASTM C 127 [17].

Figure 2. Coarse Aggregates
Source: Research data

c. Artificial Coarse Aggregates

The materials used in the manufacture of artificial coarse aggregates are Expanded Polystyrene (EPS) and Aceton. EPS is mixed with Aceton with a mixed ratio of 1:1,9. Aceton's function here is to dissolve EPS so that it can later be formed to resemble a coarse aggregate with a hard texture. The weight of this type of artificial coarse aggregates is 0,71 gr/cm^3.

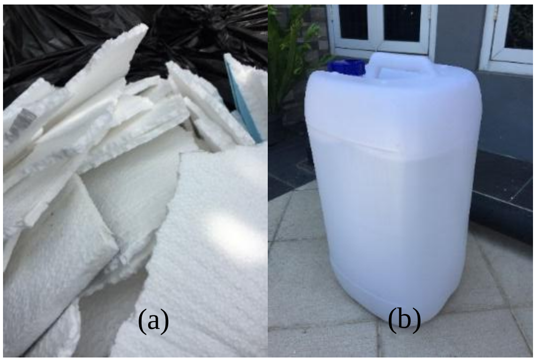

Figure 3. (a) Expanded Polystyrene (EPS), (b) Acetone
Source: Research data

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Figure 4. Artificial Coarse Aggregates
Source: Research data

d. Cement
The cement used is type 1, PPC (Portland Pozzolana Cement) in accordance with satandard ASTM C 595/595M [18].

Figure 5. Portland Pozzolana Cement
Source: Research data

e. Steel Fibers
The steel fibers used are a hooked end type. These steel fibers have a diameter of 0.8 mm, a length of 60 mm, an aspect ratio (l/d) of 75 mm, and has a tensile strength of 1254 N/mm^2.

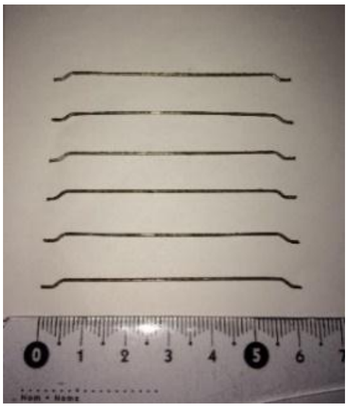

Figure 6. Steel Fibers
Source: Research data

2.2 Samples

The number of samples used in this study was 24 test objects consisting of several mixtures. This research focuses on the use of a mixture of Artificial Coarse Aggregates (ACA) and the addition of Steel Fibers (SF). The sample used is a cylinder with a size of 100 m x 200 mm. The details of the sample can be seen in table 1.

Table 1. Compressive Strength Testing Sample

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Code of Sample	Composition of Sample	Number of Sample
A0	0% ACA + 0% SF	3
A15	15% ACA + 0% SF	3
A50	50% ACA + 0% SF	3
A100	100% ACA + 0% SF	3
ASF0	0% ACA + 0.75% SF	3
ASF15	15% ACA + 0.75% SF	3
ASF50	50% ACA + 0.75% SF	3
ASF100	100% ACA + 0.75% SF	3
	Total	24

Source: Research data

2.3 Testing Procedure

Stress-strain data is obtained through the results of the compressive strength test. This compressive strength test uses a Universal Testing Machine (UTM) type HT-2101 which has a load capacity of 2000 kN. The compressive strength testing stage refers to the ASTM C 39M standard [19]. During the process of testing the surface of the sample to be given a load must be in a flat state and the sample is given a load until the condition is destroyed. The automatic testing machine will record the results of stress and strain after the concrete is finished testing press.

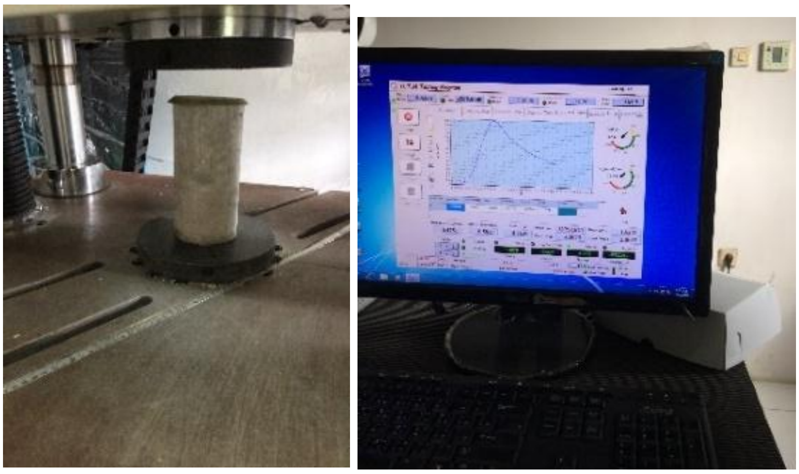

Figure 7. Universal Testing Machine dan Program
Source: Research data

2.4 Data Analysis

Experimental data was used to determine a mathematical model of stress-strain from the results of concrete compressive strength testing using a mixture of artificial coarse aggregates and steel fibers. The calculation of this mathematical model uses the help of *Ms. Excel* software. The final results of this data analysis are used as a basis for concluding this study so that it can be known the difference in stress-strain press concrete with artificial coarse aggregates and steel fibers theoretically and experimentally.

2.5 Stress-Strain Curve Formulation

The compressed stress-strain curve from the concrete compressive strength test results will be expressed in some form of the equation. The corresponding equation to describe the concrete compress stress-strain curve is the one proposed by Popovic (1973) [20]. The equation in question is as follows:

$$\frac{f_c}{f'_{ca}} = \frac{\varepsilon_c}{\varepsilon'_{ca}} \text{x} \frac{n}{n-1+\left(\frac{\varepsilon_c}{\varepsilon'_{ca}}\right)^n} \quad (1)$$

$$n = 0.8 + \frac{f'_{ca}}{17} \quad (2)$$

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where,
f'_{ca} = maximum compressive stress of concrete with EPS and Steel fibers (MPa)
f'_c = compressive stress (MPa)
ε_c = compressive strain
ε'_{ca} = compressive strain when it reaches maximum stress
n = curve fitting factor

The equation used to calculate press strain when it reaches the maximum stress (ε'_c) refers to *Chinese National Standards* GB50010-2010 [21]. The equation in question is as follows:

$$\varepsilon'_{ca} = 0.002 + 0.5(f'_{ca} - 50) \text{ x } 10^{-5} \quad (3)$$

where,
ε'_{ca} = compressive strain when it reaches maximum stress
f'_{ca} = maximum compressive stress of concrete with EPS and Steel fibers (MPa)

3. Results and Discussions

The results of the compressive test were analyzed to find out the experimental and theoretical comparison of concrete using a mixture of artificial coarse aggregates and steel fibers. Data obtained from press testing there is data on stress and strain ranging from the initial condition to the concrete destroyed. The behavior of the concrete stress-strain relationship is seen through 3 conditions *i.e.* at *the time of 0.85f'c* after the peak stress [22], *0,5f'c* after peak stress [23] and when it reaches the maximum stress. The results of the analysis of stress-strain behavior can be seen in table 2.

Table 2. Stress-Strain Compressive Concrete Experimental Test Results.

Code of Sample	Stress (σ)			Strain (ε)		
	$f'c_{maks}$ (MPa)	$0.85f'c$ (MPa)	$0.5f'c$ (MPa)	ε_{fcmaks}	$\varepsilon_{0.85f'c}$	$\varepsilon_{0.5f'c}$
A0	33.5	28.5	16.7	0.0014	0.0017	0.0018
A15	22.5	19.1	11.2	0.0013	0.0017	0.0023
A50	15.0	12.7	7.5	0.0012	0.0017	0.0025
A100	11.9	10.1	5.9	0.0011	0.0017	0.0025
ASF0	36.3	30.8	18.1	0.0016	0.0018	0.0027
ASF15	27.2	23.1	13.6	0.0016	0.0018	0.0027
ASF50	19.4	16.5	9.7	0.0014	0.0019	0.0028
ASF100	13.5	11.5	6.8	0.0013	0.0015	0.0028

Source: Research data

Table 2 shows the results of the concrete test consisting of the stress (σ) and strain (ε) values. The resulting stress value is influenced by the composition of the artificial coarse aggregates. The stress strength decreases as the composition of the artificial aggregate increases. However, the greater the percentage of artificial coarse aggregates also increases the resulting strain value. The results of the stress-strain behavior analysis are shown in a curve that can be seen in figure 8.

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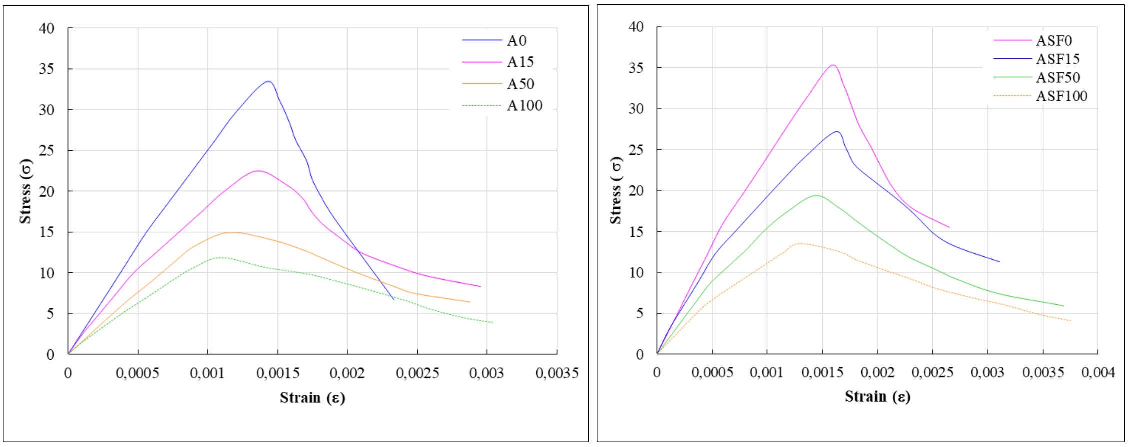

Figure 8. Compressive Stress-Strain Curve of Concrete Experimental Test Results
Source: Research data

Based on figure 8, concrete without a mixture of artificial coarse aggregates and steel fibers produces maximum compressive strength. However, concrete with a mixture of 100% artificial coarse aggregates produces greater strain. The increase in strain from normal concrete when the condition is *0,8f'c* is 2.6%, while when the condition is *0.5f'c* the increase is 35% from normal concrete. Concrete with the addition of steel fibers without the use of artificial coarse aggregates produces maximum stress. However, when viewed from the strain value, concrete with a mixture of 100% artificial coarse aggregates and 0.75% steel fibers increased by 4.5%.

To find out the results of the analysis theoretically need to make some modifications to Equation 2. This is because the material used in each concrete composition is different. Modification in Equation 2 is by modifying the value *n* into the following equations:

$$n = 0.8 + \frac{a}{f'_{ca}} \quad (4)$$

Constant *a* of Equation 4 is derived from the results of trial and error. The constant *a* used is the closest between the experimental and theoretical curve lines.

Table 3. Modify Value *n*.

Code of Sample	Modify value *n*
A0	$n = 0.8 + \frac{300}{f_{ca}}$
A15	$n = 0.8 + \frac{95}{f_{ca}}$
A50	$n = 0.8 + \frac{35}{f_{ca}}$
A100	$n = 0.8 + \frac{25}{f_{ca}}$
ASF0	$n = 0.8 + \frac{200}{f_{ca}}$
ASF15	$n = 0.8 + \frac{90}{f_{ca}}$
ASF50	$n = 0.8 + \frac{65}{f_{ca}}$
ASF100	$n = 0.8 + \frac{40}{f_{ca}}$

Source: Research data

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Based on table 3, the results of the modification of the value of *n* can be described as stress and strain curves so that experimental and theoretical differences can be seen. The lower the artificial coarse aggregates composition, the lower the constant value. The experimental and theoretical comparison curves for Compressive Stress-Strain in Concrete with a Mixture of Artificial coarse aggregates and 0% Steel fibers can be seen in figure 9.

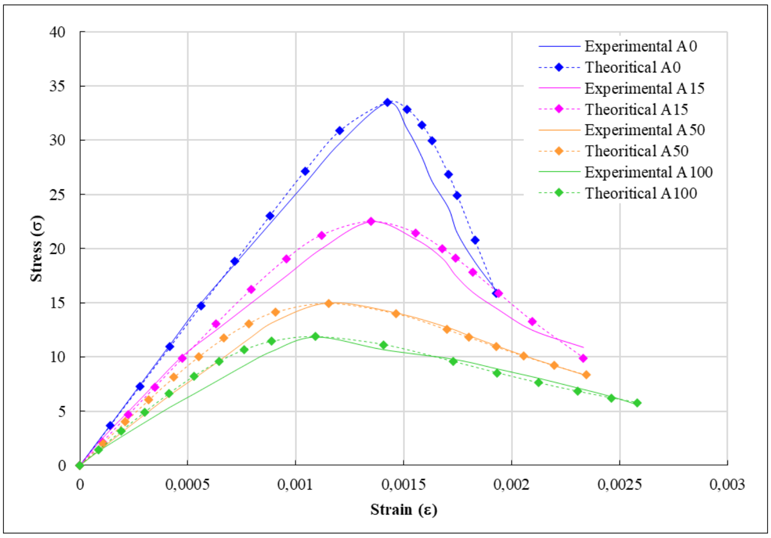

Figure 9. Experimental And Theoretical Comparison Curves Of Concrete With Artificial Coarse Aggregates
Source: Research data

Figure 9 is a comparison of the stress-strain curves from experimental and theoretical results in concrete with a mixture of artificial coarse aggregates. Based on the results of mathematical modeling from trial and error results at constant a by table 3, the stress-strain curve that is closest to the experimental is obtained. Comparison curve of experimental and theoretical compressive stress-strain of concrete with a mixture of artificial coarse aggregates and 0,75% steel fibers can be seen in figure 10.

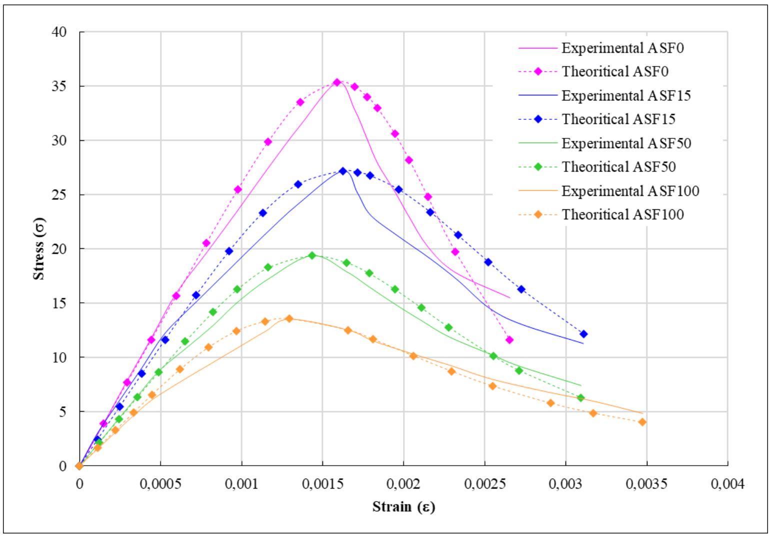

Figure 10. Experimental and Theoretical Comparison Curve Of Concrete with Artificial Coarse Aggregates And 0.75% Steel Fibers
Source: Research data

The use of artificial coarse aggregates greatly affects the value of the resulting stress. The less the composition of artificial coarse aggregates, the smaller the value of *a* in modification *n*. The use of the value of *a* in the modification of the value of *n* used based on the results of trial and error is the closest between experimental and theoretical. Based on the

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comparison curve between experimental and theoretical in figures 9 and 10, it can be seen that the optimum composition affects the stress and strain values. In concrete without steel fibers, the optimum composition that is close to normal concrete is concrete with 15% artificial coarse aggregates (A15). For concrete with the addition of steel fibers, the stress-strain curve that is close to normal concrete is concrete with a mixture of 15% artificial coarse aggregates and 0,75% steel fibers.

4. Conclusion and Suggestion

4.1 Conclusion

Concrete with a mixture of artificial coarse aggregates has more brittle properties but is not able to increase the stress value significantly. Based on the results of experimental and theoretical analysis, the addition of steel fibers to the artificial coarse aggregates mixed concrete was able to increase the strain value by 39% from normal concrete. The increase in the value of strain indicates that the properties of concrete with a mixture of artificial coarse aggregates and the addition of steel fibers become more ductile. Based on the results of the theoretical analysis, the mathematical model is influenced by the composition of the artificial coarse aggregates mixture for the strain value. The results of experimental and theoretical comparisons of the composition of the mixture that is considered to be closest to the stress-strain curve of normal concrete are concrete with a mixture of 15% ACA and concrete with a mixture of 15% ACA and 0.75% steel fibers.

4.2 Suggestion

It is necessary to do further research related to the use of fiber with a mixture of artificial coarse aggregates, for example by replacing other types of fiber such as polypropylene fiber and processing EPS as artificial coarse aggregates.

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