Reka Buana : Jurnal Ilmiah Teknik Sipil dan Teknik Kimia, 8 (1), 2023, page 30 - 40

Tersedia *online* di https://jurnal.unitri.ac.id/index.php/rekabuana

ISSN 2503-2682 (*Online*)
ISSN 2503-3654 (Cetak)

# Tegangan dan Regangan pada Beton Memadat Sendiri dengan Menggunakan ALWA Sebagai Substitusi Agregat Kasar

## *(Stress and Strain on Self-Compacting Concrete using ALWA as Coarse Aggregates Substitution)*

**Dhiafah Hera Darayani [1], Fedya Diajeng Aryani [2]**

[1] Civil Engineering, Faculty of Engineering, Al-Azhar Islamic University – Unizar Street No. 20 Turida, Mataram
[2] Civil Engineering, Faculty of Engineering, Gunung Rinjani University – Raya Mataram Street - Anjani, East Lombok

## ARTICLE INFO

**Article history**
Received : 15 November 2022
Revised : 10 January 2023
Accepted : 25 February 2023

**DOI :**
https://doi.org/10.33366/rekabuana.v8i1.4524

**Keywords:** *artificial lightweigh aggregate; self-compacting concrete; strain; stress; styrofoam*

**e-mail the corresponding autho**
fedyadiajeng@gmail.com

## ABSTRAK

Beton dengan agregat ringan merupakan salah satu jenis beton yang banyak digunakan pada daerah rawan gempa. Bahan penyusun beton ringan dengan memanfaatkan limbah salah satunya berbahan *Styrofoam.* Penggunaan *styrofoam* pada beton ringan mulai banyak digunakan pada bangunan yang bersifat struktur. Beton memadat sendiri adalah jenis beton yang memiliki kemampuan untuk mengalir dengan sendirinya tanpa mengalami segregasi. Beton beragregat ringan diaplikasikan pada beton memadat sendiri agar mendapatkan manfaat dari segi ekonomi dan waktu pelaksanaan konstruksi, sehingga lebih menghemat biaya dan waktu pengerjaan. Tujuan penelitian ini untuk mengetahui tingkat daktilitas beton dilihat dari besarnya nilai tegangan dan regangan pada setiap kadar ALWA sebagai pengganti kerikil pada beton normal dan beton memadat sendiri. Pembebanan suatu silinder beton mempengaruhi hubungan antara tegangan dan regangan. Variasi komposisi ALWA yang disubstitusi pada beton yaitu dari 0%, 15%, 50% sampai 100%. Pengujian yang dilakukan berupa kuat tekan dengan benda uji berbentuk silinder dimensi tinggi 200 mm dan diameter 100 mm. Hasil dari pengujian menunjukkan nilai regangan 0.5f'c pada SCC0, SCC15, SCC50, SCC100 nilainya yaitu 0.00140, 0.00140, 0.00146, 0.00151, semakin tinggi ALWA yang disubstitusi dalam campuran SCC maka semakin besar nilai regangannya. Selain itu, semakin tinggi jumlah ALWA yang disubstitusi dalam campuran SCC maka semakin rendah tingkat *workability*. Penelitian ini menunjukkan penggunaan agregat ringan dengan *styrofoam* dapat menjadikan beton lebih daktail daripada sebelumnya.

## PENERBIT

**UNITRI PRESS**
Jl. Telagawarna, Tlogomas-Malang, 65144, Telp/Fax: 0341-565500



## *ABSTRACT*

*Concrete with lightweight aggregates is a type of concrete that is widely used in earthquake-prone areas. One of the building blocks for lightweight concrete utilizing waste is Styrofoam. Styrofoam in lightweight concrete began to be widely used in structural buildings. Self-compacting concrete is a type of concrete that can flow by itself without experiencing segregation. Light aggregate concrete is applied to self-compacting concrete in order to get benefits from an economic and construction time perspective, thereby saving costs and processing time. This study aimed to determine the ductility level of concrete seen from the magnitude of the stress and strain values at each ALWA content as a substitute for gravel in regular and self-compacting concrete. The loading of a concrete cylinder affects the relationship between stress and strain. Variations in the composition of ALWA substituted in concrete, from 0%, 15%, 50%, to 100%. The test was carried out as compressive strength with a cylindrical specimen with a height dimension of 200 mm and a diameter of 100 mm. The results of the test show that the strain values of 0.5f'c at SCC0, SCC15, SCC50, and SCC100 are 0.00140, 0.00140, 0.00146, 0.00151, the higher the ALWA substituted in the SCC mixture, the greater the strain value. In addition, the higher the amount of substituted ALWA in the SCC mixture, the lower the level of workability. This study shows that lightweight aggregate with Styrofoam can make concrete more ductile.*

**Cara Mengutip :** Darayani, D. H., Aryani, F. D. (2023). Stress and Strain on Self-Compacting Concrete using ALWA as Coarse Aggregates Substitution. *Reka Buana : Jurnal Ilmiah Teknik Sipil dan Teknik* Kimia, 8(1), 30-40. doi:https://doi.org/10.33366/rekabuana.v8i1.4524

## 1. INTRODUCTION

Lightweight concrete using Styrofoam began to be used in structural construction, especially on beams, columns, and plates [1]. Where the requirements for structural lightweight concrete must not exceed the maximum weight of concrete 1840 kg/m3 and must meet the compressive strength and tensile strength requirements of lightweight concrete for structural purposes. The minimum compressive strength of earthquake-resistant building construction should not be less than 20 MPa [2]. Self-compacting concrete may flow naturally, while concrete made with lightweight aggregate is a great way to lessen the dead load on structures. Because of the lower cost and potential for faster processing, the combination of self-compacted concrete with lightweight aggregate concrete offers benefits in terms of cost and construction time [3].

One of the disadvantages of lightweight concrete mixtures that use Styrofoam material is the difficulty of spreading the matrix, in this case, it is the spread of fine aggregate and cement to fill the empty spaces between the grains of light material or Styrofoam so that the matrix that functions as a binder for the material is also reduced. The addition of superplasticizers can increase the abrasion of concrete, in this case, superplasticizers can increase the value of the slump so that the matrix can spread and form more bonds such that the concrete's compressive strength improves.

This research utilizes Styrofoam waste in the surrounding environment. Styrofoam will be used as coarse aggregate by dissolving it first using acetone; after that, it will be transformed into granules to resemble gravel. The use of Styrofoam that is dissolved and shaped to resemble coarse aggregate is one of the important factors that can affect the compressive strength of concrete, this is the reason for developing research on the effectiveness of using Artificial Light Weight Aggregate (ALWA) made from Styrofoam on the level of ductility seen from the magnitude of the stress and strain value in Self Compacting Concrete (SCC) with the consideration of being able to make concrete lighter but has sufficient ability to be capable of withstanding the pressure placed on it.

### Self Compacting Concrete

Waste marble (MW) and recycled aggregate (RA) from crushed concrete were used in the study on SCC. Crushed limestone aggregates (LS) are used for control in a variety of water-to-binder ratios. Later, MW or RA was used in place of LS with a 100% ratio. Fresh concrete was used for the initial testing, which included slump flow, the J-ring test, unit weight, and air content. Compressive strength, splitting-tensile strength, voltage correlation, and modulus of elasticity are the following tests. The comparison to the stress-strain curve of SCC with LS, lesser strength and higher strain resistance is produced in SCC with RA and MW aggregates. Additionally, the lower strength of MW and RA causes a drop in the modulus of elasticity relative to SCC when LS is replaced with them. On the other hand, for various grades of SCC spanning from 15 to 56 MPa, a matching linear correlation between E-moduli and compressive strength is derived [4].

In the study using 3 sizes of EPS granules, namely passing through a sieve or sieve no. 7, sieve no. between 4 and 7, and filter no. 4. In SCCs, especially those using EPS light aggregates, the recommended amount of water used is 0.35 of the mixed volume. The findings indicated that the kind of SCC is influenced by the size of EPS, if the size of EPS is getting smaller then the nature of SCC will decrease [5].

**Styrofoam**

Studying the compressive strength of Self Compacting Lightweight Concrete (SCLC) when Expanded Polystyrene Aggregate (EPS) is substituted for concrete volume by 10%, 15%, 22.5%, and 30%. The findings indicated that the volume weight and compressive strength produced decreased with increasing EPS use. From highest to lowest, compressive strength is 27 MPa, 22 MPa, 19 MPa, and 17 MPa [6].

The study used various variations in Styrofoam levels with percentages of 0%, 12%, 14%, 16%, 18%, and 20% with toluene solvent liquid from the weight of gravel used and with FAS 0.5. The highest concrete compressive strength test results occurred in the use of Styrofoam content of 12% with Toluene solvent liquid of 23.1 MPa and the use of 20% Styrofoam caused the highest rise in the value of the modulus of elasticity, which was 4672 MPa, or an increase of 21.2309% [7].

**Stress and Strain**

Studies reviewed how much influence high temperature has on stress and strain behavior in concrete. Concrete is modeled with a quality of 25 MPa which is then simulated with a constant temperature with temperature variations from 100°C, 200°C, 300°C, 400°C, 500°C, 600°C to 700°C. The results showed that at a temperature of 700°C the strain of concrete at maximum stress increased to 423% of the strain under normal conditions [8].

In research on the effect of dimensional variations in diameter and height of cylindrical test objects on the correlation of stress and strain in Self-compacting concrete (SCC) with high-volume fly ash (HVFA), it was found that HVFA-SCC can last longer so that it collapses longer when compared to conventional concrete which tends to be more brittle. HVFA-SCC has a greater ductility value than conventional concrete [9].

Concrete modeling using the ABAQUS program for stress-strain distribution results shows distribution results that are following laboratory test results, especially on the magnitude of the modulus of elasticity seen due to the stress and strain correlation curve of concrete. However, there is a difference in the maximum compressive strength results achieved between the two tests [10].

Analysis of stress and strain and deflection at the joints of reinforced concrete column beams using static loads using six test specimen samples. Static loads are placed in the center of the beams and columns until a crack pattern is obtained. The resulting strain stress correlation is different for each model, where PCR-6 (square beam type with circle column, column lateral load, interior joint type) is the model that has the largest stress value [11].

The effect of variations in the calculation impact of reinforced concrete columns' stress and strain on the ductility of the cross-section is unfettered. The correlation between stress and strain was analyzed using 4 methods (Kent and Park, Popovics, Thorenfeldt, and Hognestad). The greater the area of longitudinal reinforcement, the ductility value decreases, and the greater the quality of concrete, the ductility value also increases [12].

## 2. RESEARCH METHODS

### Artificial Lightweight Aggregate (ALWA) Creation

At the ALWA formation stage, the materials that need to be prepared are Styrofoam and Acetone solution. The following are the steps to create ALWA [13]:

1. Styrofoam is cut into small pieces, then given acetone solution, with a ratio of acetone and styrofoam mixture of 1: 1.9.
2. Giving acetone to Styrofoam is done gradually, then formed into granules.
3. After forming into granules, ALWA is soaked in a bath filled with water for ± 3 days so that ALWA quickly dries and the texture hardens.
4. ALWA that has been soaked for ± 3 days is drained and then aerated for ± 14 days at a temperature of 27º so that ALWA becomes dry.
5. Prepare a mortar mix with a ratio of sand: cement: water: adhesive (1: 1: 0.25: 0.025)
6. After that ALWA is coated with a mixture of mortar and allowed to dry until dry. Here is a picture of ALWA before being coated and after being coated with mortar.

**Figure 1. ALWA before coated and after mortar coated**

### Making Conventional Concrete and Self Compacting Concrete (SCC)

Specifications for lightweight aggregates of structural concrete refer to ASTM C330 [14]. The steps in making concrete cylinder test objects are making artificial lightweight aggregate (ALWA); further procurement of sand, cement, gravel (crushed stone), and superplasticizer materials in addition to SCC; preparing cylinder molds with a 20 mm height and a 10 mm diameter; prepare and weigh the materials used in predetermined proportions; after weighing, sand, cement, crushed stone, and ALWA materials are stirred thoroughly; then added water, for SCC the use of water is mixed first with a superplasticizer; The thoroughly mixed materials are then fed into a cylindrical mold; then the specimen is dried for the hardening process; After 24 hours, the cylindrical mold is opened and the concrete is soaked for 28 days from the time the concrete is finished molding.

**Test Specimen Curing**

The treatment method used in this study was to soak concrete samples in a bath filled with water for 28 days. This is done to maintain the moisture of the concrete so that it does not experience cracks due to the process of water loss that is so fast [15].

## 3. RESULTS AND DISCUSSION

To assess the degree of ductility of concrete is used the strain value that occurs from the part of the curve that descends after the peak. To describe the descending curve, 2 points are used, namely 0.85f'c and 0.5f'c. According to Kent and Park, the slope after the peak point is determined by the strain when the stress has fallen at 0.5f'c. The peak points' stress and strain values, 0.85f'c and 0.5f'c are shown in the following table.

**Table 1. Stress and strain values at peak point, 0.85f'c and 0.5f'c in conventional concrete**

| No. | Test specimens | Stress | | | Strain | | |
|---|---|---|---|---|---|---|---|
| | | 0.50 f'c (MPa) | 0.85 f'c (MPa) | f'c max (MPa) | □ 0.50 f'c | □ 0.85 f'c | □ f'c max |
| 1 | C0 | 11.356 | 19.306 | 22.713 | 0.00104 | 0.00099 | 0.00094 |
| 2 | C15 | 10.567 | 17.964 | 21.134 | 0.00115 | 0.00104 | 0.00090 |
| 3 | C50 | 9.697 | 16.486 | 19.395 | 0.00118 | 0.00101 | 0.00081 |
| 4 | C100 | 8.279 | 14.074 | 16.558 | 0.00142 | 0.00099 | 0.00079 |

Table 1. shows that the strain value of 0.5f'c on the C0 specimen is 0.00104, where this strain value is lower when compared to the strain value on the C100 specimen which is 0.00142. This shows that the more ALWA is used, the greater the stretch value, thus indicating a better ductility level. For more details, the link between the peak point's stress value and strain value, 0.85f'c and 0.5f'c in conventional concrete is shown in Figure 2.

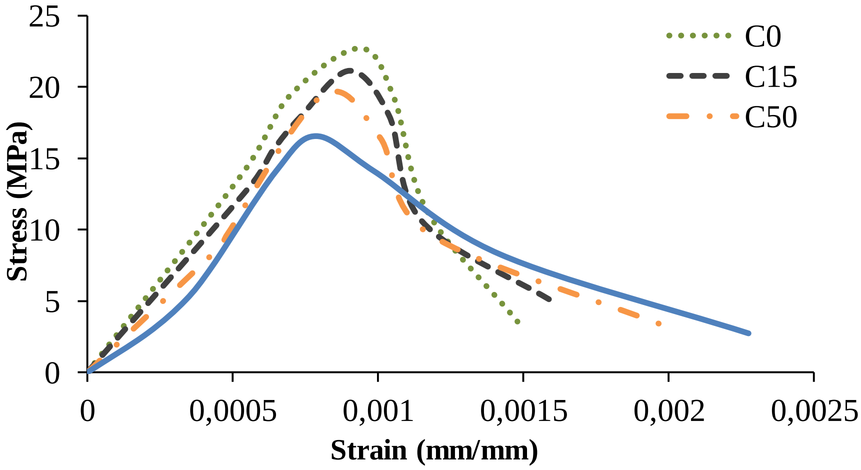



**Figure 2. Graph of stress and strain values at peak points, 0.85f'c and 0.5f'c in conventional concrete**

From Figure 2. It is evident that the C100 specimen has a more ramps curve image when compared to C0, this shows that concrete without the addition of ALWA has brittle properties while concrete with the addition of ALWA is more ductile.

**Stress and Strain Correlation in Self-Compacting Concrete (SCC)**

The stress and strain values at the cusp point, 0.85f'c and 0.5f'c in SCC concrete are shown in the following table.

**Table 2. Stress and strain values at peak point, 0.85f'c and 0.5f'c in SCC**

| No. | Test specimens | Stress | | | Strain | | |
|---|---|---|---|---|---|---|---|
| | | 0.50 f'c (MPa) | 0.85 f'c (MPa) | f'c max (MPa) | ε 0.50 f'c | ε 0.85 f'c | ε f'c max |
| 1 | SCC0 | 16.625 | 28.263 | 33.251 | 0.00140 | 0.00127 | 0.00119 |
| 2 | SCC15 | 14.167 | 24.084 | 28.335 | 0.00140 | 0.00121 | 0.00111 |
| 3 | SCC50 | 10.621 | 18.056 | 21.242 | 0.00146 | 0.00107 | 0.00095 |
| 4 | SCC100 | 9.494 | 16.139 | 18.988 | 0.00151 | 0.00123 | 0.00093 |

Table 2. shows that the strain values of 0.5f'c at SCC0, SCC15, SCC50, and SCC100 are 0.00140, 0.00140, 0.00146, and 0.00151 respectively, this indicates that the more ALWA used, the higher the ductility level. For more details, the correlation between stress and strain values can be seen in Figure 3. the following.

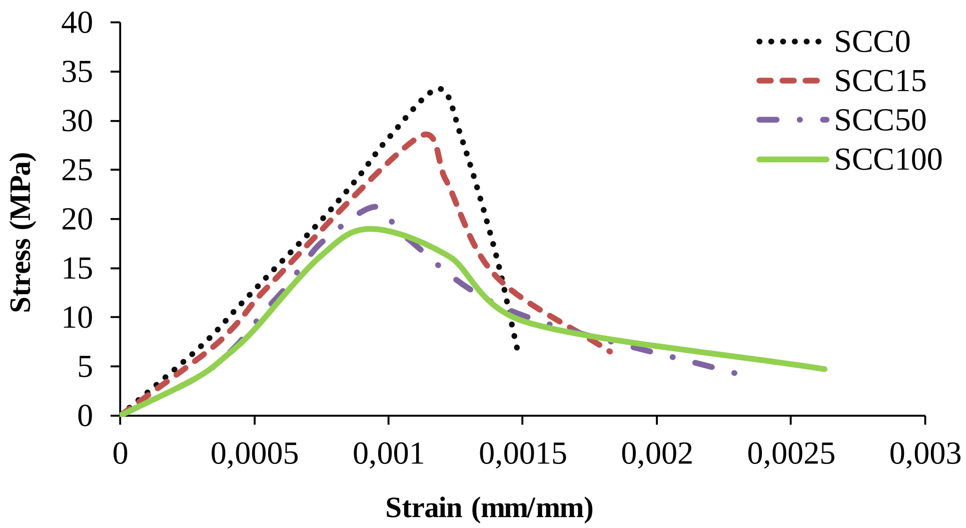



**Figure 3. Graph of stress and strain values at peak points, 0.85f'c and 0.5f'c in SCC**

Figure 3 shows that the more ALWA is used, the more the stretch stress curve ramps. The SCC0 specimen has a higher voltage with its lower stretch value at 0.5f'c when compared to SCC100. This shows that with the addition of ALWA, ductility in concrete will increase.

This study shows that the ductility value of self-compacting concrete (SCC) is greater than that of conventional concrete. The findings of this research are consistent with the results of research carried out by F. Rindang Nur Insyiroh and A. Setiya Budi Senot Sangadji, where in their research High Volume Fly Ash (HVFA) – Self Compacting Concrete (SCC) has a greater ductility value than conventional concrete.

**Strain Stress Formula**

To explain the behavior amid the tension and pressure of unconfined concrete, a formula is used based on the Popovics S equation. The equation used is based on experimental results following the conditions in this study. Here is the equation used:

$$fc = f'_{ca} \times \frac{\varepsilon_c}{\varepsilon'_{ca}} \times \frac{n}{n-1+(\frac{\varepsilon_c}{\varepsilon'_{ca}})^n} \quad (1)$$

$$n = 0.8 + \frac{f'_{ca}}{17}$$

with:

$f_c$ = concrete stress
$f'_{ca}$ = maximum stress of ALWA concrete
$\varepsilon_c$ = concrete strain
$\varepsilon'_{ca}$ = strain when the maximum stress of concrete ALWA
n = *curve fitting factor*

The strain equation in this study refers to the National Standard of China (GB 50010-2010). The equation can be seen as follows:

$$\varepsilon'_{ca} = 0.002 + 0.5(f'_{ca} - 50) \times 10^{-5} \quad (2)$$

Equation n is used following the conditions of this study, then the equation n is obtained to be:

$$n = 0.8 + \frac{a}{f'_{ca}}$$

Where the constant a is obtained from the results of trial and error so that the curve formed theoretically is close to the curve of experimental results. The value of constant a will decrease as the amount of ALWA used increases. For the formula n for each ALWA level is shown in Table 3.

**Table 3. N value in conventional concrete and self-compacting concrete**

| ALWA levels | Conventional Concrete | Self Compacting Concrete |
|---|---|---|
| 0% | $n = 0.8 + \frac{300}{f'_{ca}}$ | $n = 0.8 + \frac{700}{f'_{ca}}$ |
| 15% | $n = 0.8 + \frac{200}{f'_{ca}}$ | $n = 0.8 + \frac{400}{f'_{ca}}$ |
| 50% | $n = 0.8 + \frac{100}{f'_{ca}}$ | $n = 0.8 + \frac{150}{f'_{ca}}$ |
| 100% | $n = 0.8 + \frac{60}{f'_{ca}}$ | $n = 0.8 + \frac{100}{f'_{ca}}$ |

The theoretical and experimental shape of the correlation of strain and stress in SCC and conventional concrete is shown in Figure 4 and Figure 5 below.

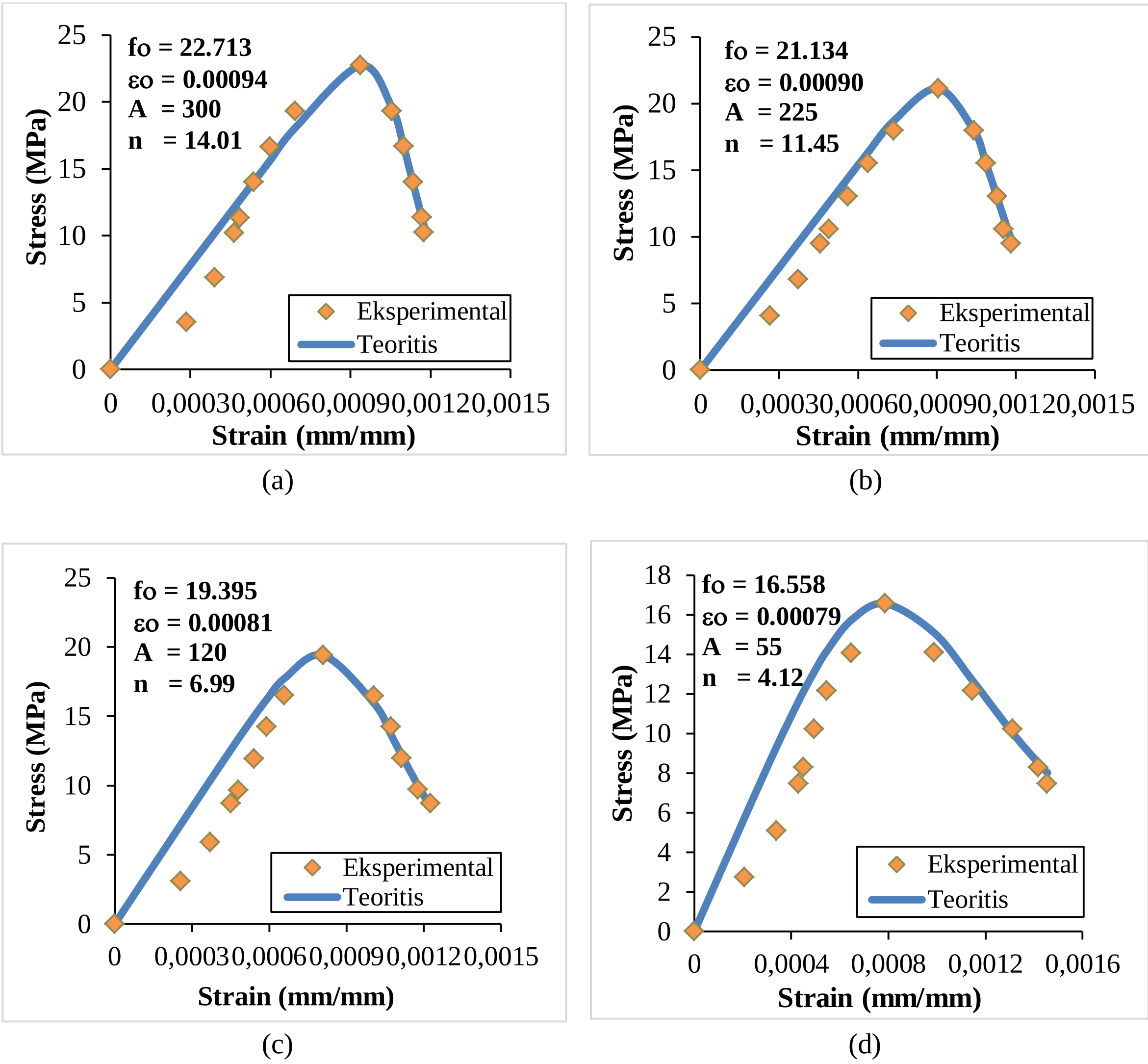
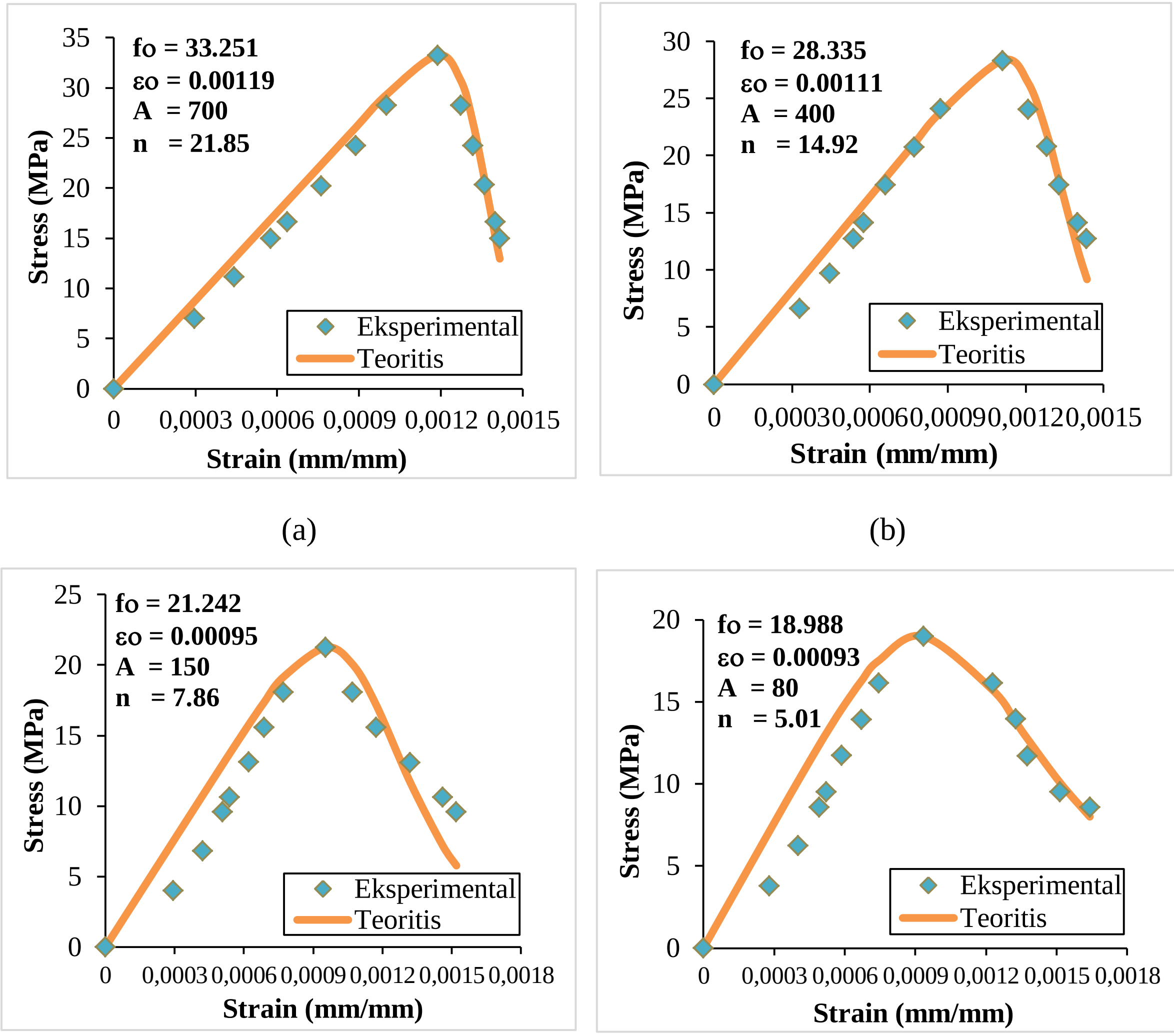



**Figure 4. Graph of the correlation between stress and strain theoretically and experimentally in conventional concrete**

Figure 4. consists of graphs (a) The correlation between stress and strain theoretically and experimentally in conventional concrete ALWA content 0%, (b) The correlation between stress and strain theoretically and experimentally in conventional concrete ALWA content 15%, (c) The correlation between stress and strain theoretically and experimentally in conventional concrete ALWA content 50% and (d) The correlation between stress and strain theoretically and experimentally in conventional concrete ALWA content 100%. Considering Figure 4. It is evident that the smaller the constant A, the smaller the value of n, but the distance between the theoretical curve and the experimental curve is getting farther. The theoretical and experimental correlation between stress and strain on SSC is shown in Figure 5. the following.




(c) (d)

**Figure 5. Graph of the correlation between stress and strain theoretically and experimentally on SCC**

Figure 5. consists of graphs (a) The correlation between stress and strain theoretically and experimentally on SCC0, (b) The correlation between stress and strain theoretically and experimentally on SCC15, (c) The correlation between stress and strain theoretically and experimentally on SCC50 and (d) The correlation between stress and strain theoretically and experimentally on SCC100. Figure 5. shows that the smaller the constant A the value of n the smaller and it is evident that the more the ALWA levels used in concrete, the graph of the correlation between stress and strain theoretically the farther away from the graph of experimental results.

## 4. CONCLUSION

The results of the test show that the strain values of 0.5f'c in SCC0, SCC15, SCC50, and SCC100 are 0.00140, 0.00140, 0.00146, and 0.00151 respectively, the more ALWA used in the SCC mixture the greater the strain value. In addition, from the results of the study, it was found that the workability level of self-compacting concrete (SCC) decreases as more ALWA is substituted. The outcomes of this research are in line with the development of science because the outcomes of this research show the use of lightweight aggregate with Styrofoam can make concrete more ductile than before.

## 5. BIBLIOGRAPHY


[1] E. S. Sunarsih and T. L. Adi Sucipto, "Tinjauan Penambahan Limbah Styrofoam Dan Fly Ash Terhadap Berat Jenis, Kuat Tekan Dan Kuat Lentur Beton Ringan Struktural," *Jurnal Ilmiah Pendidikan Teknik dan Kejuruan*, vol. 7, no. 2, 2017, doi: 10.20961/jiptek.v7i2.12690.

[2] Badan Standardisasi Nasional, "Sni 2847-2019," *Persyaratan beton struktural untuk bangunan gedung dan penjelasan*, no. 8, 2019.

[3] B. Vakhshouri and S. Nejadi, "Mix design of light-weight self-compacting concrete," *Case Studies in Construction Materials*, vol. 4, 2016, doi: 10.1016/j.cscm.2015.10.002.

[4] B. Topçu and A. Gürhan, "Use of waste marble and recycled aggregates in self-compacting concrete for environmental sustainability," vol. 84, 2014, doi: 10.1016/j.jclepro.2014.06.019.

[5] A. H. Modaraei, Rahmatmadandoust, and Nesaz Bijan, "Properties of Fresh Lightweight Self-Compacting Concrete Containing Eps Beads," *Indian Journal of Fundamental and Applied Life Sciences*, vol. 5, pp. 2706–2713, 2015.

[6] M. M. Ranjbar and S. Y. Mousavi, "Strength and durability assessment of self-compacted lightweight concrete containing expanded polystyrene," *Materials and Structures/Materiaux et Constructions*, vol. 48, no. 4, pp. 1001–1011, 2015, doi: 10.1617/s11527-013-0210-6.

[7] N. Simamora and M. H. Harahap, "Pengaruh Penambahan Styrofoam Dengan Pelarut Toluena Terhadap Kuat Tekan dan Modulus Elastisitas Beton Ringan," *Jurnal Einstein Prodi Fisika FMIPA Unimed*, vol. 3, no. 1, 2015.

[8] R. Suryanita, W. Rahmadhan, and A. Kamaldi, "Pemodelan Perilaku Tegangan dan Regangan Beton pada Suhu Tinggi dengan Software LUSAS," 2019.

[9] F. Rindang Nur Insyiroh and A. Setiya Budi Senot Sangadji, "Pengaruh Ukuran Spesimen Terhadap Hubungan Tegangan dan Regangan Pada Beton High Volume Fly Ash Self Compacting Concrete," *e-Jurnal MATRIKS TEKNIK SIPIL*, pp. 56–62, 2018.

[10] M. Narto Wijaya, "Evaluasi Tegangan dan Regangan dengan Pemodelan Silinder Beton," *Rekayasa Sipil*, vol. 12, no. 1, pp. 58–63, 2018.

[11] H. Prayuda, M. D. Cahyati, and B. Soebandono, “Analisis Tegangan Regangan dan Defleksi pada Sambungan Balok-Kolom Beton Bertulang Menggunakan Beban Statik,” 2018.

[12] P. Variasi Perhitungan Tegangan dan Regangan Kolom Beton Bertulang terhadap Daktilitas Penampang Takterkekang, P. H. Simatupang, and G. D. Siallagan, “Pengaruh Variasi Perhitungan Tegangan Dan Regangan Kolom Beton Bertulang Terhadap Daktilitas Penampang Tak Terkekang,” 2018.

[13] ASTM, “ASTM C33/C33M − 18: Standard Specification for Concrete Aggregates,” 2018.

[14] ASTM C330, “ASTM C330-17a. Standard Specification for Lightweight Aggregates for Structural Concrete,” *Annual Book of ASTM Standards*, vol. 552, no. 18. 2017.

[15] ASTM C39, “ASTM Standard C39/C39M-16, Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens,” 2016.