

# Constitutive Laws of the Reinforced Concrete Beam with the Onyx Waste Aggregate

Edhi Wahjuni Setyowati<sup>1</sup>, Wisnumurti<sup>2</sup>, Raharjo B.A<sup>3</sup>

<sup>1,2</sup>Departement of Civil Engineering, University of Brawijaya, Malang 65145, Indonesia

<sup>3</sup>Departement of Civil Engineering, State Polytechnic of Malang, Indonesia

<sup>1</sup>atitwahjuni57@gmail.com

<sup>2</sup>wsmurti@ymail.com

<sup>3</sup>bobby\_asukma@polinema.ac.id

**Abstract-** Onyx waste as additional aggregate in a concrete mix will enhance the compressive strength and elasticity modulus of the concrete material, eventually resulting in the change of behavior and strength of the concrete beam structure and also skew the constitutive law of reinforced concrete structure plan, especially in a reinforced concrete beam. The magnitude of stress tensile coefficient of tensile block used as a reference for reinforced concrete beam structure plan will also differ.

This study compared cylinder beam and reinforced concrete beam made from the Tulungagung onyx waste aggregate materials with cylinder beam and reinforced concrete beam made from crushed stone waste according to the established rules. The test results showed the difference in concrete strength, level of elasticity modulus and stress tensile coefficient of the tensile block. The difference of  $\beta_1$  coefficient shown in the outcome of the tensile analysis of the test blocks was 1.14% for concrete made from normal aggregate and 0.3% for concrete made from onyx waste aggregate.

**Keyword-** constitutive law, RC beam, onyx waste

## I. INTRODUCTION

Study of onyx waste usage has been directed for the onyx waste to be optimally used thus having economic value and support the development of Tulungagung Indonesia. One alternative way to use onyx waste is by employing it as an aggregate of the concrete mixture. Concrete made by coarse onyx aggregate inevitably differ from concrete made from the normal aggregate. The difference of aggregate type will, eventually, change the concrete strength parameters.[8],[9],[10],[11],[12],[13][14]

The difference and shift of nature and strength between normal concrete and onyx concrete became the reason for routine evaluation of concrete strength planning, especially for reinforced concrete structure. Evaluation of commonly used reinforced concrete beam is important for having a better result of strength measurement analysis.

## II. LITERATURE STUDY

### A. Onyx waste aggregate

*Marble Institute of America [1]* described onyx as a mixture of microcrystalline, comprised of coarse calcite and aragonite. This microcrystal formed as fibril and lamellar textured-materials. Often, this stone appears as translucent materials with various projecting colors depend on the composition of various ferrous oxide. The yellowish brown color is the most common result of the ferrous oxide presence. However, sometimes we can also see the whitish, pale yellow, honey yellow, red and dark green color.

### B. Modulus of Elasticity of Concrete

Nawy [2] explained that an elasticity modulus is a number describing a parameter of material strength and resistance of force-derived elastic deformation in materials. In general, elasticity modulus can be achieved through a diagram of stress and strain, defined as the curvature slope on an elastic deformation area. In concrete, the stress and strain curve is the arc appeared on the early loading phase. Therefore the elasticity modulus (modulus young) of this material is the conjunction line of the stress and strain curvature on the center point. The conjunction line slope is defined as the early tangential modulus, which can also be used for every other point within stress and strain curve. The slope of a straight line that connecting one central point to some level of stress (about 0.4  $fc'$ ) is called pressure elasticity modulus of concrete.

ASTM C469 – 02 [3] explained the calculation of elasticity modulus chord ( $E_c$ ) as:

$$E_c = \frac{S_2 - S_1}{\epsilon_2 - 0,00005} \text{ (MPa)} \quad (1)$$

with :

- $S_2 = 0,4 f_c'$
- $S_1 =$  stress in association to the longitudinal strain
- $\epsilon_2 =$  longitudinal strain of  $0,4 f_c'$

C. Stress and strain curvature of concrete

Many studies have been done to develop a formula to achieve better stress and strain curve. The equation of stress and strain curve of concrete studied by Popovics [4] and Thorensfeldt et al. [5] gave us stress strength of 15 to 125 MPa. The correlation between the resulting stress ( $f_c$ ) and the determined strain is as below:

$$\frac{f_c}{f_c'} = \frac{n \left(\frac{\epsilon_c}{\epsilon_0}\right)}{n - 1 + \left(\frac{\epsilon_c}{\epsilon_0}\right)^{nk}} \quad (2)$$

with :

- $f_c' =$  maximum stress on test cylinder (psi)
- $\epsilon_0 =$  strain level in maximum stress
- $n =$  curve adjustment factor  
 $= E_c / (E_c - E'c)$
- $E_c =$  concrete elasticity modulus
- $E'c = f_c' / \epsilon_0$

$k =$  factor determining the elevation of the curve; for  $\epsilon_c / \epsilon_0$  less than or similar to one then  $k = 1$  ; for  $\epsilon_c / \epsilon_0 > 1$  then  $k = 0.67$  . All in psi.

D. Equivalent block stress of concrete

Tae yi [6] explained that Koenen (1866) is the first person demonstrating the theory of ultimate flexure capacity failure. He hypothesized that the stress distribution on the plane of a reinforced concrete beam is linear and uniform. Emperger (1904), and later modified by Whitney (1942), proposed an equivalent square to simplify the calculation of stress distribution theory. The distribution value of pressure stress block that occur on reinforced concrete beam surfaces forms the parabolic curve. To calculate the volume of pressure stress block by the form of parabolic is difficult, in which the parabolic pressure stress block curve is replaced by equivalent square shaped-stress block as a way to easily estimate the pressure stress without reducing the accuracy of the calculation.

The parameter beam for equivalent stress, as explained by Tae Yi [6], is shown in Figure 1

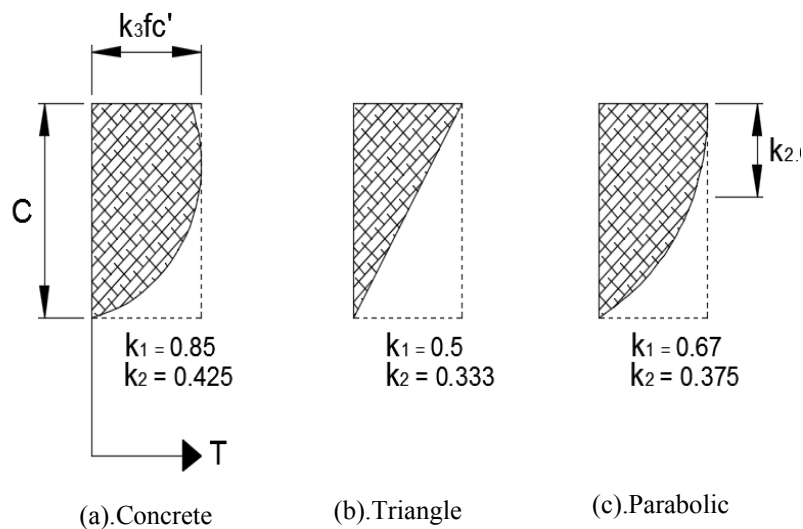


Fig 1. Details of Stress Equivalent Block Parameter

- k3 =Maximum stress ratio of blocks and the compressive strength of cylinder block ( $f_c'$ )
- k2 =Length ratio between maximum compressive fibril with the resultant of compressive strength toward neutral line
- k1 =Ratio between the curvature and rectangular surface

E. Flexure strength of reinforced concrete beam

According to Wang [7], parameters used for determining the nominal strength of square surface given only steel reinforcement consists of the width of the surface ( $b$ ), the effective height of the block ( $d$ ) and the area of steel reinforcement ( $A_s$ ). The value of the reinforced area ( $A_s$ ) has resulted from a combination of all reinforced area. Concrete mantle ( $d'$ ) functioned as the protector of reinforcing structure toward burn and external factors. Generally, the strain strength of concrete is abandoned as it usually contributes only 10% of all pressure strength. The distribution of tensile and stretch of the reinforced concrete beam (square) can be idealized as Figure 2

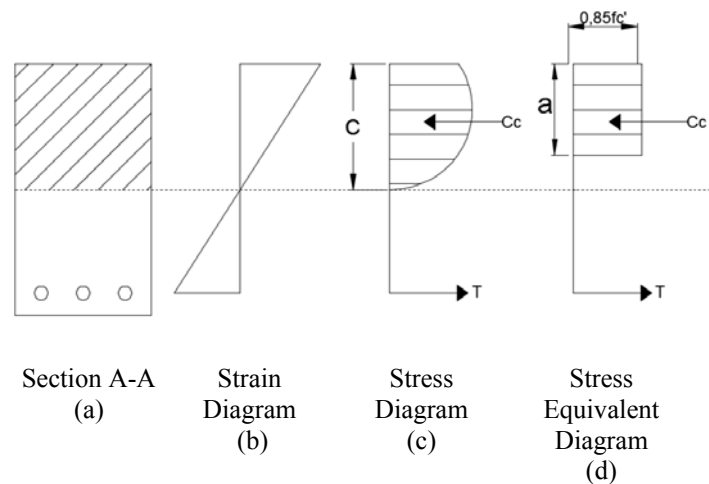


Figure 2. distribution of stress and strain on single reinforced concrete beam surface

To receive the nominal moment that can be hold by the block, the formula is as follow:

$$a = \beta_1 \times c \quad (3)$$

$$Z = (d - a/2) \quad (4)$$

$$C_c = \alpha \times f_c' \times b \times \beta_1 \times c \quad (5)$$

$$T = A_s \times f_y \quad (6)$$

In balance condition:

$$T = C_c \quad (7)$$

The nominal moment of double reinforced concrete beam

$$M_n = C_c \times Z \quad (8)$$

$$M_n = C_c (d - a/2) \quad (9)$$

With :

$C_c$  = Concrete compression

$A_s$  = steel surface used for tensile reinforcement

$b$  = Block width

$T$  = Steel tensile strength

$a$  = stress block height

$\beta_1$  = Block Equivalent

$\alpha$  = 0,85

### III. METHODOLOGY

#### A. Material investigations

To achieve the strength parameters for the arrangement process of reinforced concrete beam strength, a material test is mandatory. The material test consists of several tests below: analysis of aggregate stainer, aggregate specific weight, the weight of aggregate contain, the water level of aggregate, aggregate absorption, steel strain strength

#### B. Compressive strength test and concrete elasticity modulus

Setting of pressure strength modalities given extensometer or shortening reader tools are read for later used to have the value of available strain, as if the concrete is tested for pressure strength, and the achieved results are matched with the number of specimens of pressure test as explained above, 20 specimens for each normal concrete and onyx concrete.

#### C. Flexure strength test of reinforced concrete beam

Total test block used, size 15 cm x 25 cm x 200 cm, are 10 for each concrete with normal aggregate and those with onyx aggregate. Four point loading is used, and keep utilized until the reinforced concrete beam is damaged . Reinforced concrete beam with single and minimum reinforced by steel bar was tested with flexure load by giving load P as being described in Figure 3

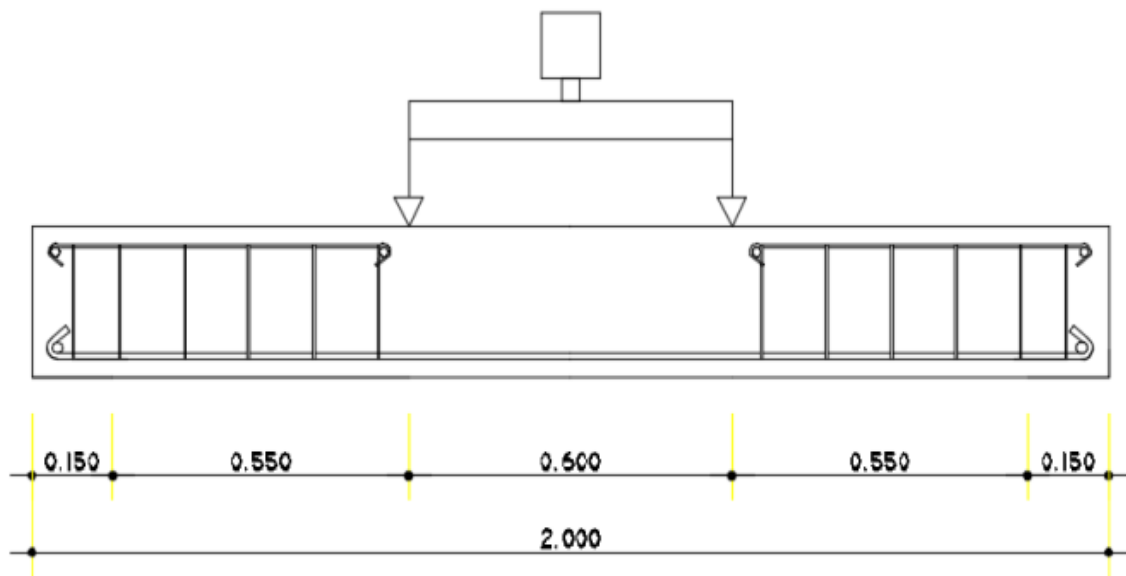


Fig 3.Reinforced Concrete beam Test Setting

#### D. Data collection methods

In this test, the data collection starts from analyzing the materials used, coarse aggregate and fine aggregate. After the test object, both the cylinder and the block, are prepared with planned quality strength of 32 Mpa and have been cured for 28 days. The initial data needed is the concrete stress test, which also to test the strain, and the result is the initial curve for stress-strain value in both normal concrete and onyx concrete. Next, a test for the block flexure strength is run within the loading frame. In the test, the data for flexure strength is collected according to the load given to the test objects. This research was done through following steps from material preparation until the deliberation of discussion and conclusion.

#### IV. RESULTS AND DISCUSSION

##### A. Compressive strength and elasticity modulus of concrete

A total of 40 cylinder test objects are used in the concrete pressure strength test, 20 objects each for concrete with coarse pebble aggregate and concrete with coarse onyx aggregate. To get the concrete strain value, while in the process, a strain measurement tool (extensometer) is applied to the cylinder. Its function is to achieve maximum strain while the concrete reaches  $f_c'$  ( $\epsilon_0$ ). Maximum strain ( $\epsilon_0$ ) is used as a parameter that applied in the analysis of equivalent compressive strain of each test object.

Modulus elasticity of normal concrete and onyx concrete is calculated from the data of stress and strain experienced from pressure strength test, where the data is collected from every load addition of 10 KN. After the data is received, the next step is to put the data into a curve graph according to the fixed load addition. Therefore we can get a good parameter of modulus elasticity analysis as in ASTM C469. Following is the pressure strength value and modulus elasticity for each of normal concrete and onyx concrete: BN: 35 722 727 702 and Average BO of 32,9227106,79 MPa.

##### B. Flexure strength of experimental reinforced concrete beam

To get the data of reinforced concrete block strength experimentally, a test of flexure strength is done to a total of 20 reinforced concrete blocks, where ten blocks are of concrete with coarse pebble aggregate (normal concrete) and another 10 of concrete blocks with coarse onyx aggregate. The test is run when the blocks are 28 days old and have been cured, measuring 25 x 15 x 200 cm, using a single reinforced system and two loading points to get the pure flexure strength. The test is done for every 200 kg of load additions.

Deflection of blocks was measured using LVDT tool that was placed in the middle of block's length. The test was run until there is 20% depreciation of the former ultimate load.

In analyzing a new block compressive stress equivalent, we need a data as per formula to get the new stress-strain value. The data required are  $f_c'$  (compressive strength of 28-days old concrete),  $\epsilon_0$  (the maximum strain of concrete strength),  $\epsilon_{cu}$ (ultimate concrete strain)and  $E_c$ (concrete modulus elasticity).

Data collected from the reinforced concrete beam testing was summarized in table 1-4. The comparison result between analysis calculation and observation result of the reinforced concrete beam was concluded in table 5-6

TABLE I. Value of Block Compressive Stress Equivalent in Normal Concrete (RC –N)

Name	$f_c'$ (MPa)	$\beta_1$
RC-N1-1	30,80	0.912
RC-N1-2	25,77	0.943
RC-N2-2	30,91	0.912
RC-N3-1	23,11	0.960
RC-N4-1	31,78	0.906
RC-N5-1	40,16	0.845
RC-N5-2	43,68	0.817
RC-N6-1	41,78	0.796
RC-N6-2	30,11	0.916
RC-N7-1	38,77	0.856
RC-N7-2	37,67	0.856
RC-N8-1	37,56	0.868
RC-N8-2	39,87	0.847
RC-N9-1	38,71	0.856
RC-N10-1	41,03	0.840
RC-N10-2	39,87	0.847
Average	35,72	0.874

TABLE II. Value of Block Compressive Stress Equivalent in Onyx Concrete

Name	fc'(MPa)	$\beta 1$
RC-O1-1	31,78	0.846
RC-O1-2	37,56	0.820
RC-O2-1	32,94	0.867
RC-O2-2	27,56	0.914
RC-O3-1	35,02	0.853
RC-O3-2	31,20	0.884
RC-O4-1	34,67	0.848
RC-O5-1	32,94	0.872
RC-O6-1	32,36	0.873
RC-O6-2	32,94	0.873
RC-O7-1	37,27	0.867
RC-O7-2	31,72	0.878
RC-O8-1	33,86	0.857
RC-O8-2	27,79	0.922
RC-O9-1	32,53	0.870
RC-O9-2	31,49	0.882
RC-O10-1	32,99	0.866
RC-O10-2	35,88	0.836
Average	32,92	0.868

Experimental flexure strength value that has been discussed in the previous chapters will be compared with the analytical flexure strength value, using the evaluated value of block compressive stress equivalent. The analytical calculation using the new  $\beta 1$  value with block measured at 15 x 20 x 200 cm and other test object details equal to reinforced concrete block experimentally. Following is the analytical value of the flexure strength:

TABLE III. Analytical Flexure Strength of Concrete with Normal Aggregate

Block Code	fc'	$\beta 1$	$\phi M_n$
	(Mpa)		Kg.cm
RC-N1	30.80	0.912	171190,89
RC-N2	30.91	0.943	171215,68
RC-N3	23.11	0.912	168966,07
RC-N4	31.78	0.960	171395,40
RC-N5	40.16	0.906	172627,16
RC-N6	30.11	0.845	171038,00
RC-N7	37.67	0.817	172266,57
RC-N8	37.56	0.796	172346,65
RC-N9	38.71	0.916	172464,76
RC-N10	39.87	0.856	172590,28

Average 171610,15

TABLE IV. Analytical Flexure Strength of Concrete with Onyx Aggregate

Block Code	fc'	$\beta 1$	$\phi M_n$
	(Mpa)		Kg.cm
RC-O1	31.78	0.846	170814,77
RC-O2	27.56	0.820	170231,50
RC-O3	31.20	0.867	171039,74
RC-O4	34.67	0.914	171561,70
RC-O5	32.94	0.853	171376,22
RC-O6	32.36	0.884	171239,70
RC-O7	31.72	0.848	171119,95
RC-O8	27.79	0.872	170381,56
RC-O9	31.49	0.873	171096,52
RC-O10	32.99	0.873	171331,80

Average 171019,35

C. Comparison of analytic versus experimental compressive strength

After we get the flexure strength value experimentally from the test result of each reinforced concrete block using the normal coarse aggregate and onyx waste, we tried to compare it to the flexure strength value of reinforced concrete block analytically using the  $\beta 1$  value that has been modified following the value modification according to the new stress-strain diagram area. The result as follows :

Table V Analytical and Experimental Flexure Strength of Normal Concrete

Block Code	Analytical Flexure Strength ( $\beta 1$ )	Experimental Flexure Strength
	Kg.cm	Kg.cm
RC-N1	171190,89	170500,00
RC-N2	171215,68	165000,00
RC-N3	168966,07	170500,00
RC-N4	171395,40	170500,00
RC-N5	172627,16	176000,00
RC-N6	171038,00	181500,00
RC-N7	172266,57	165000,00
RC-N8	172346,65	170500,00
RC-N9	172464,76	175560,00
RC-N10	172590,28	181197,50
Average	171610,15	172625,75

V. CONCLUSIONS

The conclusion of an experiment regarding the evaluation of block compressive stress equivalent ( $\beta 1$ ) in the reinforced concrete beam with onyx waste as follows:

1. Average pressure strength of concrete with normal aggregate is greater (35,72 Mpa), while the average pressure strength of concrete with onyx waste aggregate is 32,92 Mpa. Meanwhile, the average value of modulus elasticity of concrete with normal aggregate is 27277,02 Mpa, and the average value of those in concrete with onyx waste aggregate is 27106,79.
2. Average value of experimental flexure strength in normal reinforced concrete with single reinforcement is 172625,75 kg.cm. It is higher than the flexure strength value of reinforced concrete block with onyx waste aggregate that is 168300 kg.cm. This is due to some factors, such as bigger value of compressive strength and modulus elasticity in the normal concrete.
3. The value of block compressive strength equivalent ( $\beta 1$ ) with normal aggregate is higher, measured at 0,874, while the value of  $\beta 1$  in concrete with onyx waste aggregate is 0,868. This proves that the higher compressive strength in concrete is not necessarily resulting in lesser  $\beta 1$  value, but also influenced by the value of modulus elasticity and a maximum strain of both concrete types.

4. Average flexure strength of the analytic reinforced concrete beam is 172610,15 kg.cm., while that of experimental one is 172625,75 kg.cm. In the reinforced concrete beam with onyx waste, the value of analytical flexure strength is 171019,35 kg.cm, while those experimentally is valued at 168300,00 kg.cm. This shows if we make the flexure strength analysis using  $\beta_1$  value and paying attention to the compressive strength value, modulus elasticity, and the original maximum strain, we will be able to achieve a better analytical result.

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