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HIGH QUALITY ECONOMICAL CONCRETE WITH VARYING COMPOSITIONS OF RECYCLED AGGREGATE AS A SUBSTITUTION OF COARSE AGGREGATE

Rahma Nindya Ayu Hapsari[1], Bambang Haryadi[2], Agung Sutarto[3], Monica Ayu Istianti[4], Joan Rafif Panduwijaya[5], Aulia Putri Lanjarsari[6]

[1,2,3,4,5,6]Civil Engineering Study Program, Faculty of Engineering, Universitas Negeri Semarang.

e-mail: rahmanindyaayuh@mail.unnes.ac.id

ABSTRACT

The high level of infrastructure development at present forces old buildings to undergo repairs or even demolition to make way for new buildings that are more suitable and representative. The resulting demolition waste is usually discarded, becoming solid waste. The solution to the above problem is recycling the concrete waste as an alternative aggregate to replace some or all of the natural aggregates in the concrete mixture. Concrete with recycled aggregates is made with several composition variations of replacement to natural coarse aggregates, which is 0%, 25%, 35%, 45%, and 50%. The concrete will be tested for compressive strength at 28 days from the concrete mixture preparation. The research results showed that the highest compressive strength was found in the variation with a 25% replacement of natural coarse aggregates, which was 50.1 MPa, and the optimum compressive strength value is obtained at the variation of 23.51% recycled coarse aggregate substitution.

Keywords: *Recycled Aggregate; Innovation; Eco-Green Concrete; Concrete Compressive Strength; Sikament NN.*

1. Introduction

Today's rapid infrastructure development requires old buildings to be renovated or even demolished to be rebuilt with better and more representative buildings [1]. The increased use of concrete will lead to an increase in the consumption of natural aggregates and will require extraction to meet its demand, ultimately resulting in negative environmental impacts related to the availability of these aggregates in nature. In an effort to reduce the intensity of natural aggregate usage, recycled concrete aggregate is utilized as an alternative material to fill concrete mixtures. Moreover, by utilizing recycled concrete aggregate, it is possible to avoid the accumulation of waste that could have detrimental effects on the environment [2].

Recycled aggregates are materials derived from the recycling of concrete waste that can be reused in building construction and have economic value [3]. If not processed, solid waste resulting from the demolition of unused buildings can pollute the environment [4]. Construction waste can produce high-quality, environmentally friendly concrete if treated properly. The use of recycled aggregates is expected to be one of the applications that can support the green concrete program.

High-quality concrete can be produced by improving the quality of the forming material [5]. Porosity in concrete is one of the indicators to influence high quality concrete. The porosity of concrete is influenced by aggregate gradation, aggregate hardness, and cement grain fineness. Based on this, a certain percentage of recycled aggregate is used to reduce the use of coarse aggregates with

Vol. 4, No.2, p.129-139, 2023
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Publish: 25-10-2023 |

the addition of Sikament NN additive to produce environmentally friendly high strength concrete. The addition of Sikament NN additive serves to accelerate the hardening process of concrete [6]. Concrete that uses recycled aggregate substitution is expected to overcome material limitations in certain areas, save costs, and also overcome environmental problems.

2. Material & Methods

High-quality concrete can be produced by improving the quality of its constituent materials [5]. The porosity within concrete is one of the indicators that affect high-quality concrete. The porosity characteristics of concrete are influenced by aggregate gradation, aggregate hardness, and fineness of cement particles.

2.1. Recycled Aggregate

The main characteristic of recycled aggregate is material obtained from the leftover waste of the construction and concrete industry, which is then processed into coarse recycled aggregate or fine recycled aggregate [7]. Recycled aggregate refers to the use of previously used materials and processed to create new aggregates for use in construction [8]. These recycled aggregates are often obtained from demolished buildings, roadways, or other infrastructure, and they can be incorporated into new construction projects as a sustainable alternative to using natural aggregates. The use of recycled aggregates helps reduce the demand for new raw materials, conserves natural resources, and contributes to environmental sustainability. Recycled aggregates have various qualities, physical, and chemical properties.

The variability in these qualities results in differences in the properties of the concrete material produced. The previous tests conducted were on compressive strength testing and examination of concrete movement. The results of this research show, among other things, that to achieve a certain quality of concrete mixture using recycled coarse aggregate, old concrete with a higher quality than the planned concrete quality must be used. Concrete mixtures using coarse aggregate from older concrete have greater movement/shrinkage properties compared to normal concrete mixtures. In the production of concrete mixtures using crushed concrete as coarse aggregate, it is advisable to add new coarse aggregate to increase strength as well as to reduce permeability [9].

2.2. Sikament NN

Recycled aggregates with a specific percentage are used to reduce the use of coarse aggregates, accompanied by the addition of Sikament NN admixture to produce environmentally friendly high-quality concrete. The addition of Sikament NN admixture accelerates the concrete curing process [6]. Concrete utilizing recycled aggregate substitution is expected to address material limitations, cost-saving, and environmental concerns in certain areas.

Previous research on the use of recycled aggregates in concrete mixes generally tends to analyze the use of recycled aggregates as a substitute for natural coarse aggregates, aiming to evaluate the characteristics of recycled aggregates in concrete mixes alone without employing admixtures to enhance concrete compressive strength [10].

2.3. Research Method

This research activity employs an experimental method conducted in the Material and Structure Laboratory of the Department of Civil Engineering, Semarang State University. Recycled aggregates are used as a substitute for natural coarse aggregates, and Sikament NN admixture is utilized to enhance the concrete compressive strength. Concrete with recycled aggregates is produced with several composition variations for the replacement of natural coarse aggregates, namely 0%, 25%, 35%, 45%, and 50%. The concrete's compressive strength will be tested at a curing age of 28 days from the concrete mixing date. The following is the flowchart of the research as shown in the diagram below:

Vol. 4, No.2, p.129-139, 2023
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Received: 10-08-2023 |
Publish: 25-10-2023 |

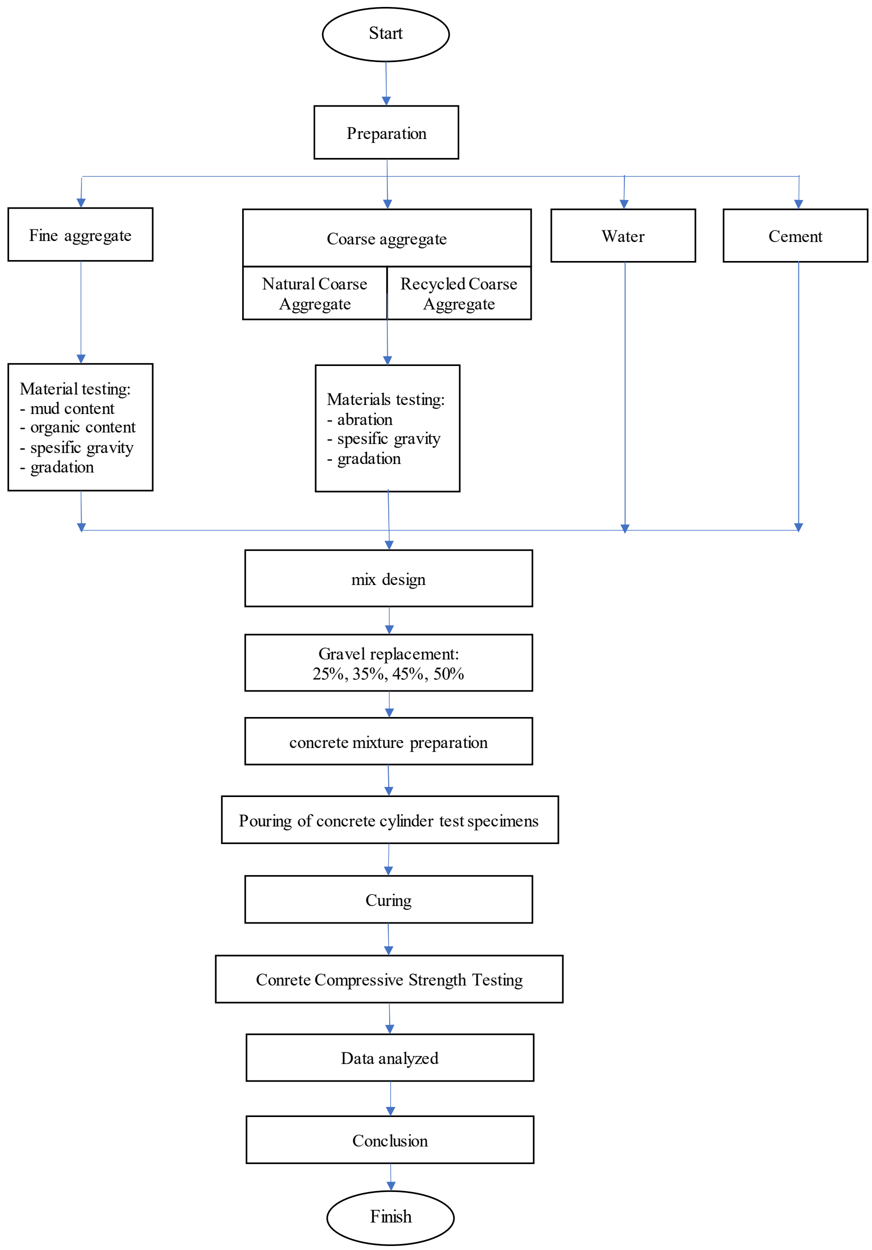

Figure 1. Flowchart of Research Stages

2.4. Data Collection Techniques

The complete stages of the research implementation are as follows:

a. Stage I, Preparation

At this stage, all materials and equipment to be used are prepared in advance so that the research can run smoothly. Making molds or formwork of test objects is also done at this stage.

JICE Journal Innovation of Civil Engineering
Vol. 4, No.2, p.129-139, 2023
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Received: 10-08-2023 |
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b. Stage II, Material test
   At this stage testing of the materials used is carried out. These tests, show whether the material to be used for the study is eligible or not when used as design data for concrete mix. This stage is tested on:
   1) Fine aggregates, among others, were tested.
      a) Mud content [11]
      b) Organic content [11]
      c) Gradation [12]
      d) Specific gravity [13]
   2) Coarse aggregate, including tests
      a) Abrasion [14]
      b) Specific gravity [15]
      c) Gradation [12]

(a) (b)

Figure 2. (a) Natural Coarse Aggregates; (b) Recycled Aggregates

c. Stage III, Preparation of mix design
   At this stage, mix design is made with a compressive strength plan of 40 MPa. The results of the mix design are used for the manufacture of concrete cylinder test specimens.
d. Stage IV, Manufacture of test specimens
   At this stage the following work is carried out:
   1) Making concrete mix [16]
   2) Testing slump test [17]
   3) Casting into formwork.
   4) Removal of test specimens from the mould [18]
e. Stage V, Testing
   At this stage, the compressive strength test that occurs due to loading at the age of 28 days is carried out [19]. This test was conducted at the Materials and Structures Laboratory of the Civil Engineering Study Program, Faculty of Engineering, Universitas Negeri Semarang.
f. Stage VI, Data analysis
   At this stage, the data obtained from the test results were analyzed to obtain a conclusion on the relationship between the variables studied in the research.
g. Stage VII, Conclusion drawing
   At this stage, the data that has been analyzed is made a conclusion related to the research objectives.

JICE Journal Innovation of Civil Engineering

Vol. 4, No.2, p.129-139, 2023
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Received: 10-08-2023 |
Publish: 25-10-2023 |

2.5. Data Analysis Technique

Tests were carried out with a Compression Testing Machine on 28-day-old test specimens by applying pressure to vertically placed test specimens until they collapsed. The applied load (P) is divided by the area of the pressed side (A) to obtain the compressive strength of the concrete.
The compressive strength is calculated by the formula:

$$f'c = P \times A \quad (1)$$

where:

f'c = concrete compressive strength of cylindrical specimen (N/mm^2)
P = max compressive load (N)
A = surface area of the cylindrical specimen (mm)

Table 1. Planning of Test Objects

Test Item Code	Composition of recycled aggregate	Composition of natural aggregate	Number of test pieces
KT0	0%	100%	3 pcs
KT25	25%	75%	3 pcs
KT35	35%	65%	3 pcs
KT45	45%	55%	3 pcs
KT50	50%	50%	3 pcs
Total			**15 pcs**

3. Result and Discussion

The method used in this research is the experimental method. Testing experiments were conducted on several mix variations to obtain a result that confirms the relationship between the variables investigated. This study aims to identify the compressive strength of concrete using recycled coarse aggregate. From this identification, the optimum level of recycled coarse aggregate content in the concrete mix will be analyzed. The following are the results of each stage of the research:

3.1. Preparation

At this stage, all materials and equipment to be used are prepared in advance so that the research can run smoothly. Making moulds or formwork of test objects is also done at this stage.

3.2. Material testing

At this stage testing of the materials used is carried out. From these tests, it can be seen whether the materials to be used for the study are qualified or not when used as data for the design of concrete mixtures.

a. Fine Aggregate Testing Results (Sand)

The tests on the fine aggregates carried out in this study included tests for mud content, organic matter content, specific gravity, aggregate gradation, and specific gravity. The results of these tests are presented in the tables below.

Vol. 4, No.2, p.129-139, 2023
Send: 08-08-2023 |
Received: 10-08-2023 |
Publish: 25-10-2023 |

Table 2. Sand test results

Test type	Test results	Standard	Conclusion
Organic content	Light yellow	Yellow	Qualified
Mud content	4 %	Max 5 %	Qualified
Bulk specific gravity	2,48 gr/cm^3	-	-
Bulk specific SSD	2,5 gr/cm^3	-	-
Apparent specific gravity	2,45 gr/cm^3	-	-
Absorbtion	1,01 %	-	-
Fine Modulus	2,79	2,3 – 3,1	Qualified

Table 3. Sand gradation test results

Sieve Diameter (mm)	Restrained			Passing Weight Cumulative (%)	Terms
	Weight (gr)	Percentage (%)	Cum (%)		
9,5	0	0	0	100	100
4,75	135	4,50	4,50	95,50	95 - 100
2,36	400	13,34	17,85	82,15	80 - 100
1,18	494	16,48	34,32	65,68	50 - 85
0,85	350	11,67	46,00	54,00	25 - 60
0,3	1193	39,79	85,79	14,21	10 - 30
0,15	250	8,34	94,13	5,87	2 - 10
0	176	5,87	100	0	0
Cum	2998	100	382,59	-	-

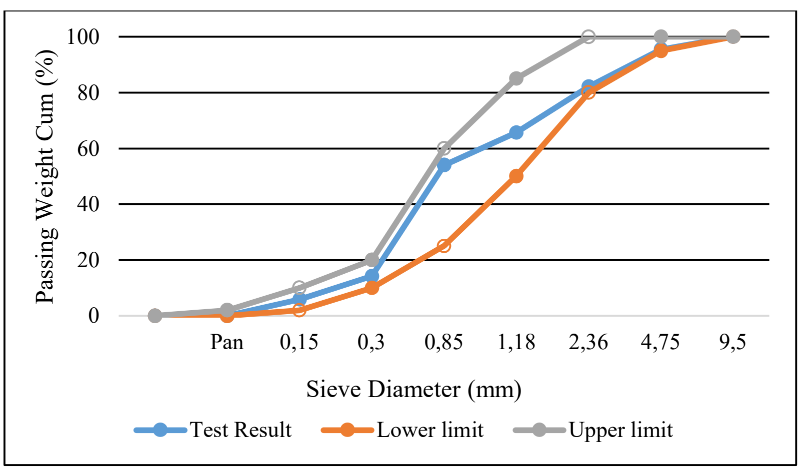

Figure 3. Fine Aggregate Gradation

b. Natural Coarse Aggregate Test Results

The testing of the split coarse aggregate (crushed stone) conducted in this research includes specific gravity test, abrasion test, and coarse aggregate gradation. The test results are

Vol. 4, No.2, p.129-139, 2023
Send: 08-08-2023 |
Received: 10-08-2023 |
Publish: 25-10-2023 |

presented in Table 6, while Table 7 provides the sieve analysis results for the coarse aggregate samples to determine their gradation.

Table 4. Natural Coarse Aggregate Test Results

Test type	Test result	Standard	Conclusion
Bulk specific gravity	2,57 gr/cm^3	-	-
Bulk specific SSD	2,68 gr/cm^3	-	-
Apparent specific gravity	2,62 gr/cm^3	-	-
Absorbtion	2,23 %	-	-
Abrasion	24,3 %	Max 50 %	Qualified
Fine modulus	5,1806	5 - 8	Qualified

Table 5. Natural Coarse Aggregate Gradation Test Results

Sieve Diameter (mm)	Restrained			Passing Weight Cumulative (%)	Terms
	Weight (gr)	Percentage (%)	Cum (%)		
1 1/2 in	0	0	0	100	90-100
1 in	155	5,86	5,86	94,14	
3/4 in	1047	16,84	22,7	77,3	35-70
1/2 in	698	13,00	35,70	64,3	
3/8 in	615	12,71	48,41	51,59	10-40
8 mm	132	23,37	71,78	28,22	
4,75 mm	0	23,23	95,01	4,99	0-5
Pan	0	4,99	100	0	0
Total	2647	100	100	0	-

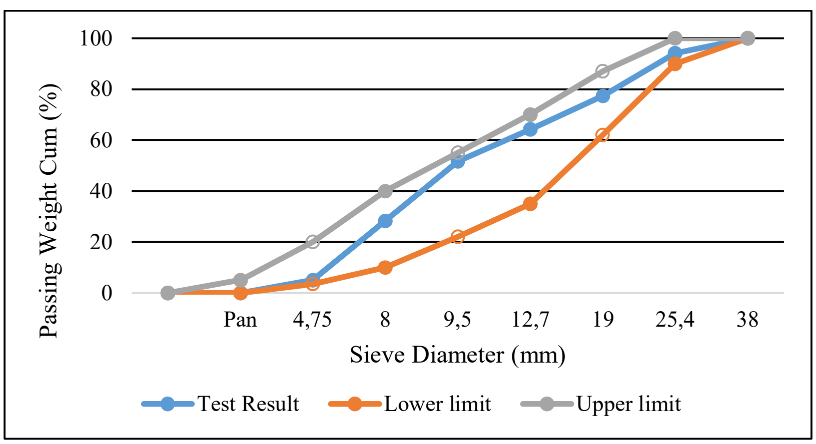

Figure 4. Natural Coarse Aggregate Gradation

c. Recycled Coarse Aggregate Test Results

The testing of recycled coarse aggregate conducted in this research includes specific gravity tests, abrasion tests, and coarse aggregate gradations [20]. The test results are presented in Table 6, while Table 7 provides the sieve analysis results for the recycled coarse aggregate samples to determine their gradation.

JICE Journal Innovation of Civil Engineering
Vol. 4, No.2, p.129-139, 2023
Send: 08-08-2023 |
Received: 10-08-2023 |
Publish: 25-10-2023 |

Table 6. Recycled Coarse Aggregate test results

Test type	Test result	Standard	Conclusion
Bulk specific gravity	2,15 gr/cm^3	-	-
Bulk specific SSD	2,33 gr/cm^3	-	-
Apparent specific gravity	2,63 gr/cm^3	-	-
Absorbtion	13,67 %	-	-
Abrasion	41,22 %	Max 50 %	Qualified
Fine modulus	5,1806	5 - 8	Qualified

Table 7. Recycled Coarse Aggregate Gradation Test Results

Sieve Diameter (mm)	Restrained			Passing Weight Cumulative (%)	Terms
	Weight (gr)	Percentage (%)	Cum (%)		
1 1/2 in	0	0	0	100	90-100
1 in	351,39	13,26	13,26	86,74	
3/4 in	575,05	21,7	34,96	65,04	35-70
1/2 in	853,30	32,20	67,16	32,84	
3/8 in	396,97	14,98	82,14	17,86	10-40
8 mm	356,69	13,46	95,60	4,4	
4,75 mm	14,31	0,54	96,14	3,86	0-5
Pan	102,29	3,86	100,00	0	0
Total	2650	100	100,00	0	-

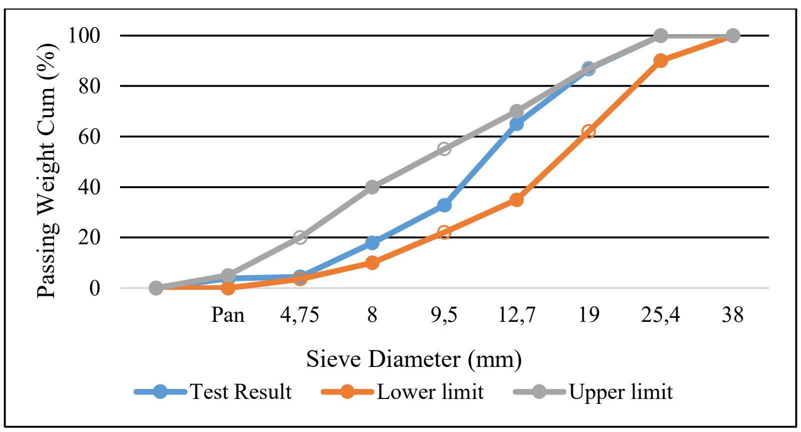

Figure 5. Recycled Coarse Aggregate Gradation

JICE Journal Innovation of Civil Engineering
Vol. 4, No.2, p.129-139, 2023
Send: 08-08-2023 |
Received: 10-08-2023 |
Publish: 25-10-2023 |

3.3. Mix Design Preparation

Table 8. Mix Design Preparation

Materials	Variation				
	Normal Concrete	25%	35%	45%	50%
Sand	737,1	737,1	737,1	737,1	731,1
Cement	327,3	327,3	327,3	327,3	323,3
Gravel	1105,6	829,2	718,7	608,1	552,8
Recycled Gravel	0	276,4	386,9	497,5	552,8
Sikament NN	4,2	4,2	4,2	4,2	4,2

3.4. Concrete Compressive Strength Testing

Following the mix design phase, the next step is the concrete casting process. For each casting session, a maximum of 6 specimens for 28-day testing can be produced. After casting is completed, the concrete will be placed in a curing tank to cure for a period of 27 days. Subsequently, the concrete specimens will be air-dried for 1 day to achieve dryness before conducting the 28-day concrete compressive strength testing.

Table 9. Concrete Compressive Strength Test Results

Specimen Code	Compressive Strength (MPa)			Average of Compressive Strength (MPa)	Total of Specimen
	1	2	3		
KT0	46,45	45,75	46,50	46,23	3 pcs
KT25	50,20	49,70	50,40	50,10	3 pcs
KT35	48,95	49,30	48,75	49,00	3 pcs
KT45	47,10	46,95	46,95	47,00	3 pcs
KT50	45,20	44,90	44,90	45,00	3 pcs
Total					**12 pcs**

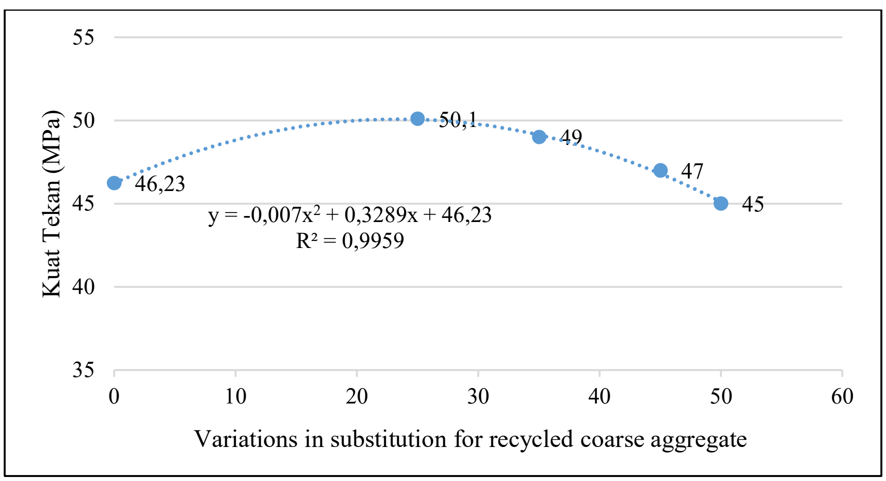

Figure 6. Concrete Compressive Strength Regression

JICE Journal Innovation of Civil Engineering

Vol. 4, No.2, p.129-139, 2023
Send: 08-08-2023 |
Received: 10-08-2023 |
Publish: 25-10-2023 |

From the regression graph above, the polynomial equation is obtained.

$$y = -0{,}007x^2 + 0{,}3289x + 46{,}23$$

where : y = concrete compressive strength
x = variation of recycled coarse aggregate substitution

The optimal value is obtained when x is at y'=0

$$\frac{dy}{dx} = 0$$

$$y' = 2\,(-0{,}007)x + 0{,}3289$$

$$y' = -0{,}014x + 0{,}3289$$

$$x = \frac{0{,}3289}{0{,}014} = 23{,}51$$

where x = variation of recycled coarse aggregate substitution

From the above calculations, it can be observed that the optimum compressive strength value is obtained at the variation of recycled coarse aggregate substitution of 23,51%.

4. Conclusion

From the conducted research and testing, it is concluded that the highest value in concrete compressive strength results is achieved at a substitution percentage of 25% recycled coarse aggregate relative to the total composition of coarse aggregate, while the lowest value in concrete compressive strength results is obtained at a substitution percentage of 50% recycled coarse aggregate relative to the total composition of coarse aggregate, and the optimum compressive strength value is obtained at the variation of 23,51% recycled coarse aggregate substitution. This is due to the increased porosity of the concrete influenced by the high absorption value of recycled coarse aggregate, wherein a higher absorption value of the aggregate will increase the water absorption capacity of the concrete mixture, leading to porous concrete and an increased concrete shrinkage value, which consequently reduces the concrete compressive strength.

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