

Compressive Strength of Concrete with Recycled Concrete Aggregate as Coarse Aggregate and Recycled Paving Block Aggregate as Fine Aggregate Partially Substituted by Recycled Brick Aggregate

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ABSTRACT— *An excessive extraction of natural resources for aggregate in concrete mix can caused an environmental degradation. According to Indonesia ministry of industry in 2017, the use of cement is predicted will reach 84,96 million tons, that can affected the use of aggregate for concrete mix are quadruplet to 250 – 350 million tons. Opimally, the use of recycled material is green method that can reduce an excessive extraction of natural aggregates and keep an environmental sustain. The aim of this study is to obtain recycled aggregate concrete compressive strength and examine recycled aggregate concrete quality in days 3, 7, 28, 35, and 90 along with a proposal of the use of recycled aggregate concrete as a building construction material. This research used experimental method of SNI 03-2834-2002 the standard of normal concrete mix design for $f'c$ 25 MPa then built five types of concrete mix of REC B, REC C, REC D, REC E, and REC F with every types of concrete has four sample are used for compressive strength test. The fine recycled paving block aggregate (RPA) were used partially to substituted a fine recycled brick aggregate (RBA) at 0%, 25%, 50%, 75%, and 100% by weighth. The result of this study showed the mixed concrete REC D with RCA 100%, RPA 50% and RBA 50% in 28 days is generate highest compressive strength than other recycle aggregates concrete mixes. Compressive strength at 28 days in a mix codes REC B, REC C, REC D, REC E and REC F are 18,12 MPa; 18,36 MPa; 19,35 MPa; 16,69 MPa; and 16,39 MPa. The results show that it is feasible to replace a natural aggregate entirely by recycled aggregates. With compressive strength over 17 MPa at 28 days, mix codes REC B, REC C and REC D are recommended to use the recycled aggregate concrete for structure of residential buildings but mix codes REC E and REC F aren't recommended and only allowed for non-structural concrete such as separate wall (SNI 8140:2016). Based on SNI 03-0691-1996 about solid brick concrete (paving block), recycle aggregate concrete with mix code of REC B, REC C, and REC D are able to use on paving block with B quality such as parking lot. While, recycled aggregate concrete with mix code of REC E and REC F are able to use on paving block with C and D quality which used for pedestrian, garden and other use.*

Keywords— compressive strength, natural aggregates, recycled aggregate, SNI 8140:2016, SNI 03-0691-1996

1. INTRODUCTION

The use of material of natural resources for concrete industry after year 2010 are reached 8 – 10 million tons per year [1]. The use of natural aggregate for concrete are estimated three or four times of cement used. According to Indonesian Ministry of Industry in 2017, the use of cement are predicted reach 84,96 million tons, that makes amount of aggregate use for concrete mix are quadruplet at 250 – 350 million tons. It was impacted the contribution of mining and excavation sector in 2016 are 2.59%, it more lower than year 2015 which are 2.81% with negative growth of -0.22% as a consequence of decreased non-renewable natural resources [2].

In these years, many researcher did study about brick waste [3]. Brick waste can be used as a coarse and fine aggregate. Many literature concur that recycled coarse aggregate from demolish bricks usually could increase concrete porosity, reduce mechanic strength and improve durability, so that for structural purpose, it needs to be careful especially

when exceed the 30% of RBA (Recycled Brick Aggregate) rate [4]. For non-structural concrete with compressive strength under 25 MPa, a concrete with more higher percentage of RBA as coarse aggregate then substitute with natural coarse aggregate are generated higher loss of compressive strength with following linear correlation. The whole substitute could affect the result of compressive strength by 45% more lower than standard concrete mix [5].

Consolidated RBA as fine aggregate also makes concrete need more water during mix process because of higher water absorption [6]. Fully substitute of standard fine aggregate with RBA as fine aggregate are lead to resistant fade in middle-strength concrete with compressive strength 40 MPa which evaluated around 30% [7]. However, interfacial transition zone between RBA and cement pasta, appearly are more relative cohesive according to morphological observe, it is due to rough surface of recycled aggregate and pozzolanic activity. Pozzolanic has effect which could improving concrete mechanical strength [8].

The use of RCA (Recycled Concrete Aggregate) as coarse aggregate could decrease compressive strength by 40%. The other effect of RCA as coarse aggregate are decreased tensile strength by 24% and modulus of elasticity by 45% with a higher long-term deformation[9].

RCA as fine aggregate has higher amount of cement pasta than RCA as coarse aggregate with a consequence of increase water absorption and decrease density [10]. The negative effect of RCA as fine aggregate, makes it very limited and even prohibited to use [11]. Because of that makes only few literature studying about RCA as fine aggregate [12]. Substitution of whole RCA as fine aggregate to standard aggregate resulting decreased of compressive strength, tensile strength, and flexural strength by 14%, 6%, and 23% [13].

The recycled aggregate which studied use material from recycle concrete waste, paving block, and red bricks that can be reused for building construction material. The aim of this study is to obtain recycled aggregate concrete compressive strength and to examine recycled aggregate concrete quality in days 3, 7, 28, 35, and 90 along with a proposal of the use of recycled aggregate concrete as a building construction material.

2. METHODOLOGY

This study was conducted in Laboratory Material and Structural Strength at Departement of Civil and Environmental Engineering of Bogor Agricultural University, Babakan Village, Dramaga District, Bogor Regency, West Java. It started from February until October 2017. Location of study area is shown in Figure 1.

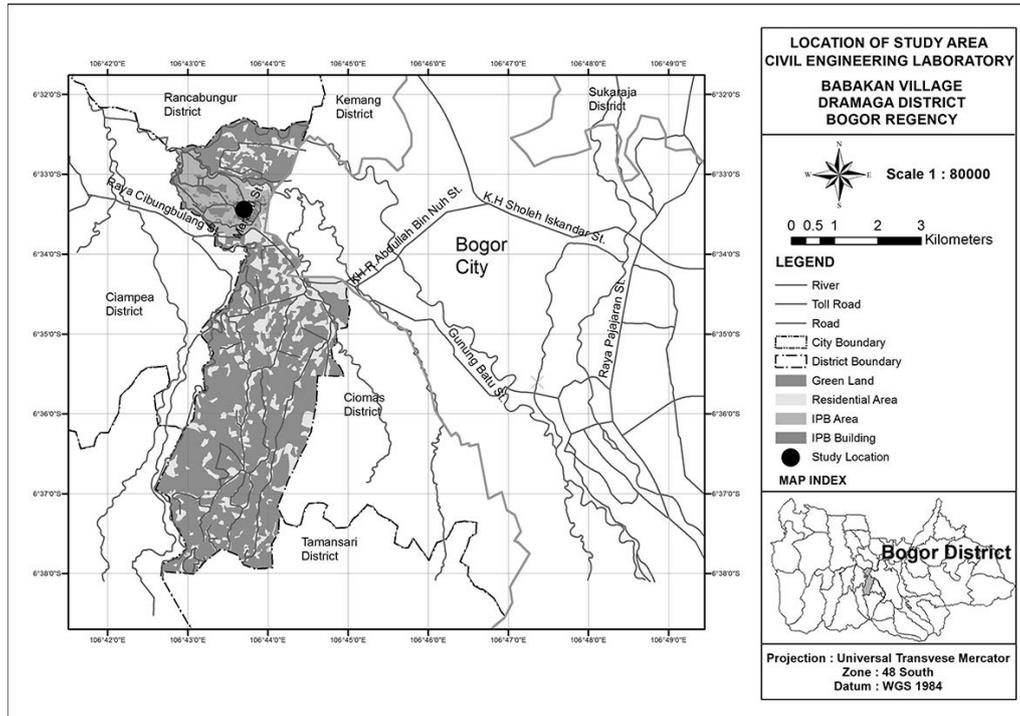


Figure 1. Location of study area

2.1 Tools and Material

This study are used tools : concrete molding equipment, slump test equipment, sand filter, bowl, universal testing machine, measuring cup, scales, vibrator, soaking tanks, wet sacks, ovens, concrete mixer, material shrink test machine and hammer test. For material used natural coarse aggregate from stone crusher industry in Cigudeg District and pieces

of structural concrete from Kebun Raya Residence housing in Bogor city. Natural fine aggregate used pieces of crushed paving block from Pasir Kuda street and pieces of crushed red brick from Kebun Raya Residence housing in Bogor city. The cement used OPC type I with green certificate from Holcim cement industry while the water used from Cihideung river which already cleaned in water treatment at Bogor Agricultural University.

2.2 Preparation Phase

Prepare whole tools and material for study in Laboratory of Material and Structural Strength of Departement Civil and Environmental Engineering of Bogor Agricultural University.

2.3 Material Test

Material test are used to obtain rough and fine aggregate material quality. List of aggregate and standard test which used are shown in Table 1. Parameters of test result are calculated using Eq. (1), (2), (3), (4), (5), (6), (7), (8), (9), and (10).

Table 1. Type of aggregate characteristic and standard use test

List of Type	Rough aggregate		Fine aggregate	
	Standard	Interval	Standard	Interval
Density and absorbtion	SNI 03-1969-2008	1.6% - 3.3%	SNI 03-1970-2008	1.6% - 3.3%
Volume	SNI 03-1973-1990	1.6 – 1.9 kg/liter	SNI 03-1973-1990	1.4 – 1.9 kg/liter
Water Content	SNI 03-1971-1990	0.5% - 2%	SNI 03-1971-1990	0.5% - 5%
Organic Content	-	-	SNI 03-2816-1992	< No.3
Mud Content	SNI 03-4142-1996	Max 1%	SNI 03-4142-1996	Max 5%
Shrink	SNI 2417-2008	Max 40%	-	-
Filter analysis	SNI 03-1968-1990	6.0 – 7.1	SNI 03-1968-1990	1.5 – 3.8

$$\text{Bulk Specific Gravity} = \frac{Bk}{Bssd - Ba} \quad (1)$$

$$SSD = \frac{Bssd}{Bssd - Ba} \quad (2)$$

$$\text{Apparent Surface Dry} = \frac{Bk}{Bk - Ba} \quad (3)$$

$$\text{Absorption} = \frac{Bssd - Bk}{Bk} \times 100\% \quad (4)$$

$$\text{Aggregate Water Content} = \frac{W2 - W5}{W5} \times 100\% \quad (5)$$

$$\text{Mud Content} = \frac{W1 - W4}{W1} \times 100\% \quad (6)$$

$$\text{Weight of Loose Aggregate} = \frac{W3}{V} \quad (7)$$

$$\text{Weight of Dense Aggregate} = \frac{W6}{V} \quad (8)$$

$$\text{Voids} = \frac{[(S \times W) - M] \times 100}{(S \times W)} \quad (9)$$

$$FM \text{ (Fine Modulus)} = \frac{\sum \text{percentage of cumulative restrain begin with filter } 150 \mu\text{m (0.15 mm)}}{100} \quad (10)$$

Where, Bk is weight of drying oven test object, SSD is weight of saturated surface of dryness test material, Ba is weight of saturated surface of dryness in water test object, B is pycnometer weight + water, BT is pycnometer weight + test object + water, $W1$ is weight of aggregate, $W2$ is weight of test object + $W3$ is weight of test object in loose condition. $W4$ is weight of aggregate above filter number 200 and 16, $W5$ is weight of drying oven test material, $W6$ is weight of compacted condition of test material, V is cylinder tube volume, S is weight of aggregate type, M is weight of aggregate volume, FM is fine modulus.

2.4 Making of Recycled Fine and Rough Aggregate

The making of fine aggregate such as natural sand, recycled red bricks and recycled paving block sand along with rough aggregate such as crushed natural stone and crushed recycle concrete must be fulfilled the standard requirement. The process of making recycled fine and rough aggregate are shown in Figure 2.

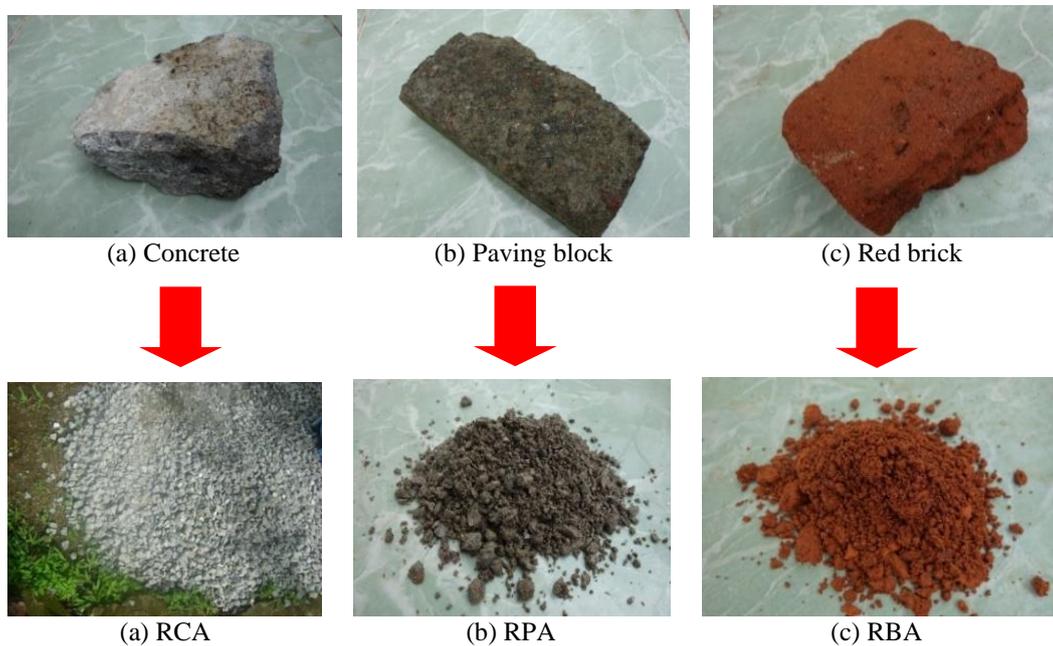


Figure 2. Process of making recycled concrete aggregate (RCA), recycled paving block aggregate (RPA), recycled brick aggregate (RBA)

2.5 Making of Test Object

In this phase, concrete sampling are making with steps: (1) fixing the mix design of concrete; (2) making concrete mix; (3) checking slump value; (4) making cylinder mold test object with diameter of 15 cm and height of 30 cm, then built four sample with different mix variety. Each test object with different variety mix are shown in Table 2. Recycle aggregate concrete mix design is based on SNI 03-2834-2002. It mentioned, in every 1 m³ of standard concrete with f^c 25 MPa is required 262.9 kg cement, 224.29 kg water, 705.58 kg fine aggregate, and 897.23 kg coarse aggregate.

Table 2. The details of sum of cylindrical test object

No.	Concrete Mix Code	Concrete ages (day)				
		3	7	28	35	90
1.	NORM A	-	-	-	-	-
2.	REC B	4	4	4	4	4
3.	REC C	4	4	4	4	4
4.	REC D	4	4	4	4	4
5.	REC E	4	4	4	4	4
6.	REC F	4	4	4	4	4
	Sum	20	20	20	20	20
	Total	100				

Where, *NORM A* is a standard concrete with natural aggregate of NA 100%, *REC B* is concrete with recycle aggregate of RCA 100% - RPA 100% - RBA 0%, *REC C* is concrete with recycle aggregate of RCA 100% - RPA 75% - RBA 25%, *REC D* is concrete with recycle aggregate of RCA 100% - RPA 50% - RBA 50%, *REC E* is concrete with recycle aggregate of RCA 100% - RPA 25% - RBA 75%, *REC F* is concrete with recycle aggregate of RCA 100% - RPA 0% - RBA 100%.

2.6 Treatment of Test Object

After 24 hours of concrete is molded, the test object must be pull out from the mold and treat the concrete with soak in water until test days is coming. Concrete treatment is used in days 3, 7, 28, 35, and 90.

2.7 Tests of Compressive Strength of Test Object

Concrete compressive strength test is performed in days 3, 7, 28, 35, and 90. Concrete compressive strength can

calculated using Eq. (11) while average concrete compressive strength can obtained using Eq (12).

$$\text{Compressive Strength} = \frac{P_{max}}{A} \quad (11)$$

$$\text{Average Compressive Strength} = \frac{\sum X_i}{n} \quad (12)$$

Where, X_i is compressive strength, X is average compressive strength, P is maximum capacity, A is area of test object, n is sum of test object.

2.8 Data Analysis

Stone pieces of coarse aggregate, natural sand of fine aggregate, concrete recycle, paving block recycle and red brick recycle are performed material test. After the result of material test are came out, researcher can continue for making concrete with accordance of SNI 03-2834-2002 the standard of normal concrete mix design for $f'c$ 25 MPa. The concrete are built in four test object with cylinder shape of diameter is 15 cm and height is 30 cm along with different variety mix and ages. The test object is performed with a curing treatment and continued with compressive strength test at days 3, 7, 28, 35, and 90 to obtain a result of concrete quality. The result of data is analyzed with Lilliefors Method and SPSS Programs. Research flowchart is shown in Figure 3.

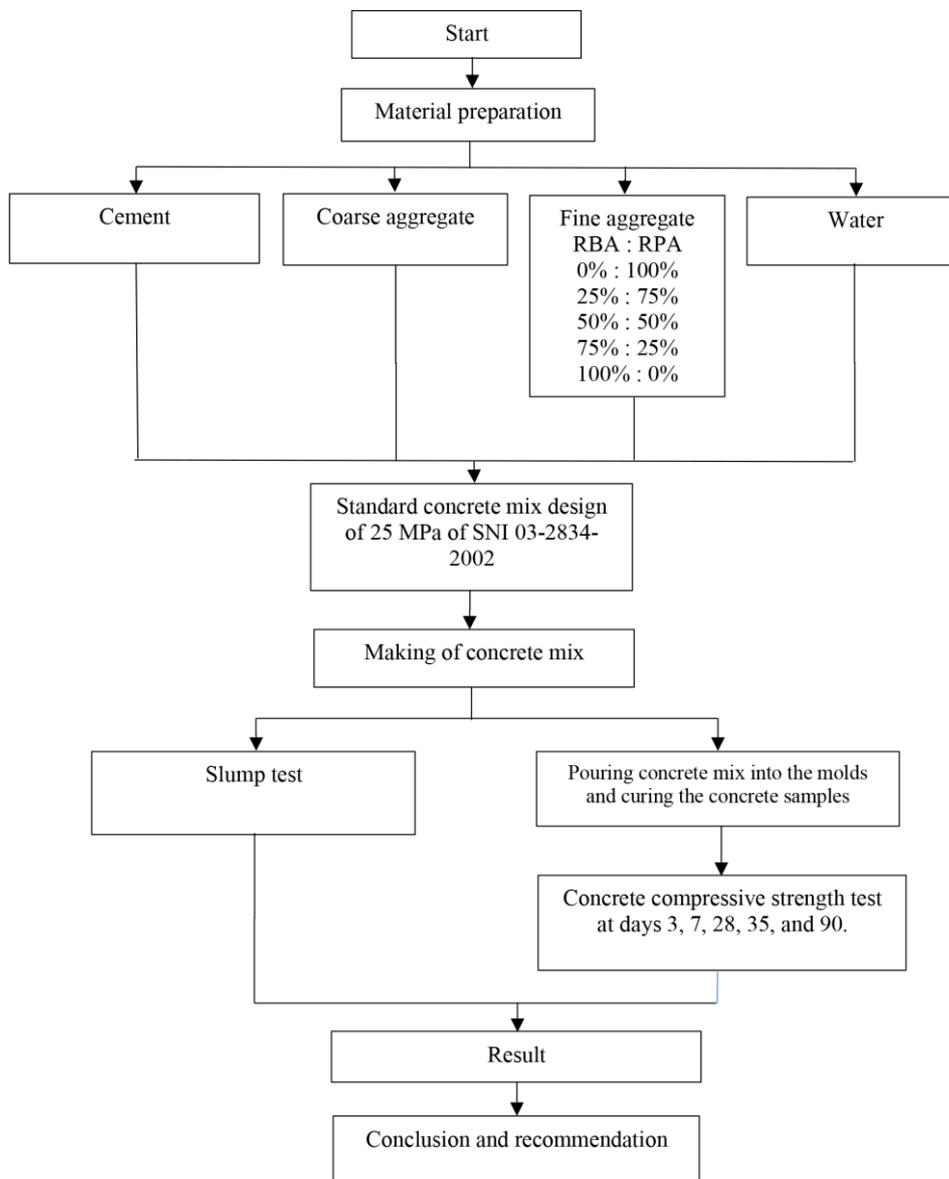


Figure 3. Flowchart research

3. RESULT AND DISCUSSION

3.1 Concrete Mix Design, Fine and Coarse Aggregate Test, Slump Test

Recapitulation of fine and rough aggregate test result are shown in Table 3 and Table 4. A slump test of each concrete samples are shown in Table 5. Compressive strength of concrete are shown in Table 6.

Table 3. Recapitulation of physical and mechanical test of natural sand

Type of Test	Test Result	Standard	Information
Mud content	3.37%	maximum 5%	qualify
Organic substance contents	NaOH solution with transparent color	transparent or light yellow	qualify
Bulk specific gravity	2.08	-	-
Bulk specific gravity (SSD)	2.18	-	-
Apperent specific grafity	2.30	-	-
Absorbtion	4.54%	-	-
Fine modulus	2.66	2.3-3.1	qualify
Water content	11.97%	-	-

Table 4. Recapitulation of crushed stone as coarse aggregate test results

Type of Test	Test Results	Standard	Information
Bulk Specific Gravity	2.53	-	-
Bulk Specific Gravity (SSD)	2.56	-	-
Apperent Specific Gravity	2.59	-	-
Absorbtion	0.88%	-	-
Water content	1.45%	-	-
Fine modulus	5.21	5 - 8	qualify
Shrink	17.17%	Maximum 50%	qualify

Table 5. Slump test results

Mix Code	Type of Aggregate	Fine aggregate substitution	Slump Value (mm)		
			I	II	Average
Normal A	natural aggregate	-	-	-	-
Rec B	recycle aggregate	brick 0%	34	36	35
Rec C	recycle aggregate	brick 25%	30	32	31
Rec D	recycle aggregate	brick 50%	27	28	27.5
Rec E	recycle aggregate	brick 75%	25	25	25
Rec F	recycle aggregate	brick 100%	23	20	21.5

From Table 5 are seen the effect of substitution of natural aggregate replaced by recycled aggregate is lowering slump value because of high water absorbtion. However, slump value result is still in designated range of 25 -50 mm except of REC F mix code is 21.5 mm.

Table 6. Compressive strength of concrete

Mix codes	Compressive strength (MPa)				
	3 day	7 day	28 day	35 day	90 day
TARGET A	10.00	16.25	25.00	26.00	30.00
REC B	12.10	15.08	18.12	20.92	22.71
REC C	8.58	12.76	18.36	19.14	23.07
REC D	9.07	12.14	19.35	20.31	24.40
REC E	10.85	13.77	16.69	18.30	20.69
REC F	12.22	14.43	16.39	17.76	19.49

The results of standard and recycled concrete compressive strength in days 3, 7, 28, 35 and 90 are shown in Figure 4. Generally, it can be seen that concrete compressive strength is increasing simultaneously with a grow concrete ages. In days 3, standard mix concrete compressive strength is 19.43 MPa, it more higher than targeted concrete with compressive strength of 10 MPa while the other five type of recycle concrete generate compressive strength under targeted concrete and standard concrete with the biggest value in REC F mix code is 12.22 MPa and the lowest value in REC C is 8.58 MPa. In days 7, standard mix concrete compressive strength is 22.35 MPa while the other five variety of recycle concrete generate compressive strength with the biggest value in REC B mix code is 15.08 MPa and the lowest value in REC D is 12.14 MPa. In days 28, standard mix concrete compressive strength is 33.93 MPa while the other five variety of recycle concrete generate compressive strength with the biggest value in REC D mix code is 19.35 MPa and the lowest value in REC F is 16.39 MPa. In days 35, standard mix concrete compressive strength is 34.69 MPa while the other five variety of recycle concrete generate compressive strength with the biggest value in REC B mix code is 20.92 MPa and the lowest value in REC F is 17.76 MPa. In days 90, standard mix concrete compressive strength is 43.11 MPa while the other five variety of recycle concrete generate compressive strength with the biggest value in REC D mix code is 24.40 MPa and the lowest value in REC F is 19.49 MPa. Comparison timeline of all recycled aggregate concrete compressive strength is shown in Figure 4.

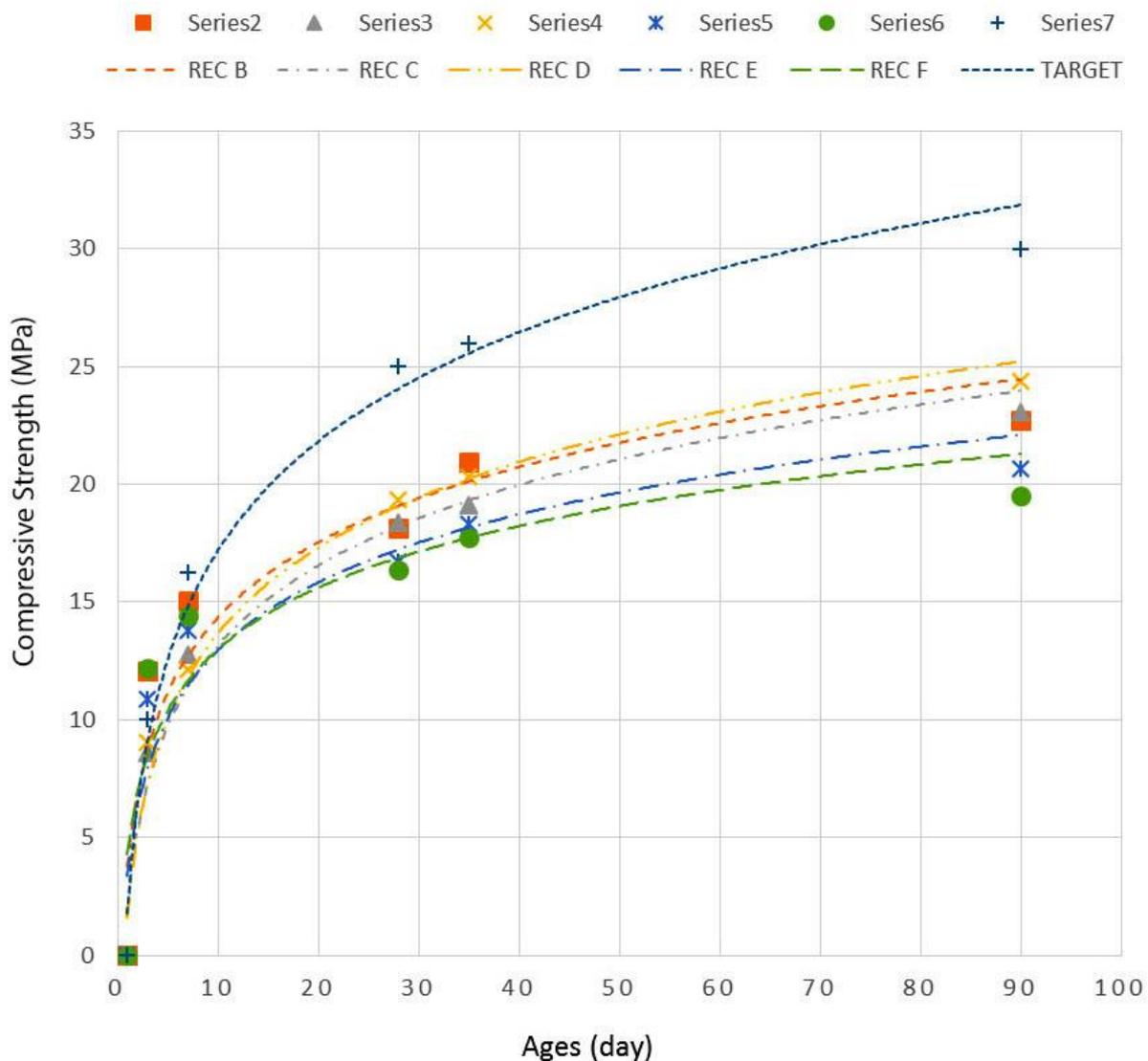


Figure 4. Comparison of timeline all recycled aggregate concrete compressive strength

From the Figure 4 are clearly shows the difference of the development of recycled aggregate concrete compressive strength which are more lower every each days compared to targeted standard concrete. The progress between recycled and standard aggregate concrete in percentage value of targeted compressive strength of 25 MPa in days 3, 7, 28, 35, and 90 are 63.7% - 96.68%, 54.99% - 68.87%, 48.66% - 56.97%, 50.70% - 59.71% and 48.21% - 59.86. The good result is seen on mix code of REC D with a composition of 100% RCA, 50% RPA, and 50% RBA in days 28 generate highest

value of recycled compressive strength of 19.35 MPa and after days 28 is showed good trend than any other recycled aggregate concrete.

4. CONCLUSION

1. REC D with a composition of 100% RCA, 50% RPA, and 50% RBA in days 28 generated highest value of recycled compressive strength of 19.35 MPa and after days 28 is showed good trend than any other recycled aggregate concrete.
2. This research results are suggested the use of recycle concrete mix codes REC B, REC C, and REC D with compressive strength over 17 MPa at 28 days, can use as a structural concrete according to SNI 8410-2016 procedural of concrete structures for housing and mix codes REC E and REC F only allowed for non-structural concrete such as separate wall. Based on SNI 03-0691-1996 about quality and test method of solid brick concrete, recycle aggregate concrete with mix code of REC B, REC C, and REC D are able to use as paving block with B quality such as parking lot. While, recycled aggregate concrete with mix code of REC E and REC F are able to use as paving block with C and D quality which used for pedestrian, garden and other use.

5. REFERENCES

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