Formula of Recycled Concrete Aggregate Compressive Strength in Mix Design

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Abstract— The development of material for concrete has advanced rapidly and many alternative aggregate as base material for concrete has found to reduce the natural aggregate that has been took from stone mining, such as recycled aggregate, ALWA (Artificial Lightweight Aggregates), glass as aggregate, and other material that can replace aggregate in the concrete. Those aggregate alternative aim to reduce the using of natural aggregate. This paper only explain recycle aggregate. The name of concrete that is made from recycle aggregate (RA) is called Recycle Concrete Aggregate (RCA). The experimental of RCA in the mix design of concrete that made from recycle concrete has been done to find out the formula of compressive strength design of concrete mix design. The sample has been made more than 100 cylinder specimens that three specimens for each strength. The variation of recycle aggregate is made from variation of normal concrete strength that is made for 25, 30, 40, 50, 65, 70 and 80 MPa and the variation of percentage of recycle aggregate contain is 50 and 100%. Base on the experiment result the strength of RCA is decrease the compressive strength from the natural concrete. The decreasing of normal compressive strength is about 20 to 25% under the original compressive strength of concrete and about 26 to 35% for high strength concrete. Keywords—component; Concrete Mix Design, Natural Aggregate (NA), Recycle Aggregate (RA), Recycle Concrete Aggregate (RCA), Compressive Strength, Normal Compressive strength of concrete, High Compressive strength of concrete.

1. Introduction

In present time, the concrete can made from many alternative of material beside natural aggregate, those are recycled aggregate, ALWA (Artificial Lightweight Aggregates), glass as aggregate, and other material that can replace aggregate the concrete. Those material will replaced a natural aggregate in the concrete. It aims to reduce the use of natural aggregate the concrete and minimize the environmental damage that mining of natural aggregate is exploited in a large quantity. The replacement of natural aggregate to recycle aggregate is expected to have a good strength in the concrete result. The name of concrete that is made from recycle aggregate is called Recycle Concrete Aggregate (RCA). The experimental of RCA has made more than 100 cylinder specimens for several variation. Those variations are combination of natural aggregate and recycle aggregate, water cement ratio, deferent treatment of aggregate that is washing and not washing and resource of original concrete compressive strength that is 25, 30, 40, 50, 65, 70, and 80 MPa. Concrete aggregate that made from resources of original concrete compressive strength is crushing from original concrete to make recycle aggregate. It aims to find out the decreasing of strength and concrete performance. All specimens has been made to get a formula to predict a compressive strength design when mixing a material in the concrete.

The variation of recycle aggregate proportion in the concrete mix refer to existing study that has been done by Schuzl, Maholtra, Frondistau-Yannas in the book writen by Dhir, et.al. [5] and Hansen [6], as follows :

1. Gradation (shape, texture and particle diameter) of recycled aggregate is same with natural aggregate;
2. The percentage variation of coarse and fine aggregate in the concrete is 50, and 100%;
3. The variation of original concrete compressive strength is 25, 30, 40, 50, 65, 70, and 80 MPa.

All of data including experiential study will be analyze in the one curve in order to gate a formula. This formula can be used to predict the compressive strength of concrete in the mix design. It also aims to facilitate and easier for user when make a concrete mix design from recycle aggregate.

2. Experimental Test Of Fine And Coarse Aggregate As Base Of Concrete Material

The experimental of recycle aggregate has been started from finding out of aggregate characteristic that refers to ASTM C-136-95a [3] such as sieve analysis, abrasion, Apparent specific gravity, Bulk specific gravity (dry), Bulk specific gravity (SSD), weigh of compacted volume, weight of loose volume, water content, water absorption, fineness modulus, soundness, mortar content in recycle aggregate, fineness content of aggregate. The experimental result can be presented in the following Table and curve.

Table 1. Experimental result of fine aggregate

Description of Testing	Natural Aggregate	Recycle Aggregate					
		Water cement ration				Ready Mix demolition	Burning building demolition
		0.4	0.5	0.6	0.7		
Apparent specific gravity	2.808	2.765	2.752	2.750	2.740	2.735	2.647
Bulk specific gravity (dry)	2.245	2.176	2.162	2.155	2.151	2.115	1.964
Bulk specific gravity (SSD)	2.445	2.364	2.358	2.352	2.348	2.342	2.220
% absorption of water	8.931	9.876	9.870	9.680	9.665	10.185	13.122
Weight of compact volume (kg/ltr)	1.558	1.223	1.218	1.214	1.215	1.208	1.146
Weight of loose volume (kg/ltr)	1.395	1.110	1.115	1.108	1.110	1.072	1.067
Maximum aggregate size (mm)	4.750	4.750	4.750	4.750	4.750	4.750	4.750
Fineness content (%)	2.500	1.300	1.250	1.150	1.200	1.400	2.000
Fineness modulus	3.114	3.285	3.148	3.245	3.211	3.332	3.290
Water content (%)	12.740	6.030	5.770	5.820	5.940	5.610	11.220
Soundness (%)	7.600	8.000	7.000	8.000	6.000	8.000	9.000

Base on the properties testing result in Table I, in generally the testing result value of recycle fine aggregate is similar with natural fine aggregate, but in the several value of recycle fine aggregate is smaller than natural fine aggregate, except the water absorption. It is caused by cement or cement paste that adhere on the surface of sand and more porous in the mortar (it can be seen in Table V). Furthermore, the natural and recycle fine aggregate will be also tested by sieve analysis as shown in Figure 1. It aims to know the gradation of fine aggregate. Base on the testing result of fine aggregate gradation, the fine recycle aggregate also meets to the ASTM C-136-95a [3] specification. So, recycle

fine aggregate can replace the natural fine aggregate, but it has to study more detail to know the characteristic of concrete that is made from recycle aggregate.

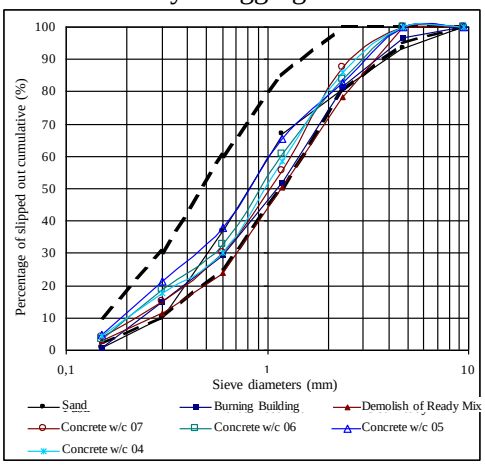

Figure 1. Gradation curve of fine aggregate

Table 2. Experimental result of coarse aggregate for w/c 0.4 & 0.5

Description of Testing	Natural Aggregate	Recycle Aggregate					
		Specimen w/c-04			Specimen w/c -05		
		5-10	10-14	14-20	5-10	10-14	14-20
Apparent specific gravity	2.701	2.703	2.521	2.674	2.710	2.534	2.682
Bulk specific gravity (dry)	2.314	2.187	2.298	3.011	2.172	2.285	2.950
Bulk specific gravity (SSD)	2.457	2.391	2.402	2.428	2.374	2.390	2.405
% absorption of water	6.175	8.485	8.150	7.972	8.512	8.192	8.025
Weight of compact volume (kg/ltr)	1.409	1.310	1.364	1.389	1.302	1.358	1.363
Weight of loose volume (kg/ltr)	1.284	1.122	1.204	1.231	1.111	1.197	1.186
Maximum aggregate size (mm)	20.000	10.000	14.500	20.000	10.000	14.500	20.000
Fineness content (%)	0.500	0.100	0.100	0.100	0.100	0.100	0.100
Fineness modulus	7.001	4.324	4.827	4.564	4.312	4.830	4.604
Water content (%)	6.560	-	-	-	-	-	-
Soundness (%)	17.600	19.800	19.800	19.800	19.900	19.900	19.900
Apparent specific gravity	2.179	5.000	6.000	6.000	6.000	6.000	6.000
Alkali reactive	Nil	Nil	Nil	Nil	Nil	Nil	Nil

Table 3. Experimental result of coarse aggregate for w/c 0.6 & 0.7

Description of Testing	Natural Aggregate	Recycle Aggregate					
		Specimen w/c-06			Specimen w/c -07		
		5-10	10-14	14-20	5-10	10-14	14-20
Apparent specific gravity	2.718	2.542	2.687	2.722	2.536	2.689	2.718
Bulk specific gravity (dry)	2.155	2.266	2.740	2.134	2.255	2.526	2.155
Bulk specific gravity (SSD)	2.390	2.349	2.399	2.355	2.333	2.392	2.390
% absorption of water	9.065	8.125	8.110	9.137	8.133	8.240	9.065
Weight of compact volume (kg/ltr)	1.288	1.345	1.324	1.259	1.311	1.324	1.288
Weight of loose volume (kg/ltr)	1.100	1.168	1.184	1.084	1.158	1.183	1.100
Maximum aggregate size (mm)	10.000	14.500	20.000	10.000	14.500	20.000	10.000
Fineness content (%)	0.100	0.100	0.100	0.100	0.100	0.100	0.100
Fineness modulus	4.402	4.825	4.606	3.850	4.852	4.592	4.402
Water content (%)	-	-	-	-	-	-	-
Soundness (%)	20.320	20.320	20.320	20.440	20.440	20.440	20.320
Apparent specific gravity	6.000	6.000	7.000	□.000	□.000	□.000	6.000
Alkali reactive	Nil	Nil	Nil	Nil	Nil	Nil	Nil

Table 4. Experimental result of coarse aggregate for ready mix & burning building

Description of Testing	Natural Aggregate	Recycle Aggregate					
		Specimen w/c-06			Specimen w/c -07		
		5-10	10-14	14-20	5-10	10-14	14-20
Apparent specific gravity	2.735	2.568	2.631	2.663	2.542	2.559	2.735
Bulk specific gravity (dry)	2.115	2.259	2.282	2.105	2.209	2.303	2.115
Bulk specific gravity (SSD)	2.342	2.439	2.474	2.314	2.430	2.463	2.342
% absorption of water	10.185	8.029	8.486	9.059	8.808	6.947	10.185
Weight of compact volume (kg/ltr)	1.208	1.286	1.324	1.146	1.210	1.322	1.208
Weight of loose volume (kg/ltr)	1.072	1.149	1.179	1.067	1.065	1.164	1.072
Maximum aggregate size (mm)	10.000	14.500	20.000	10.000	14.500	20.000	10.000
Fineness	0.100	0.100	0.100	0.100	0.100	0.050	0.100

Description of Testing	Natural Aggregate	Recycle Aggregate					
		Specimen w/c-06			Specimen w/c -07		
		5-10	10-14	14-20	5-10	10-14	14-20
content (%)							
Fineness modulus	3.467	5.983	4.373	2.857	6.787	5.506	3.467
Water content (%)	-	-	-	-	-	-	-
Soundness (%)	22.200	22.200	22.200	28.200	28.200	28.200	22.200
Apparent specific gravity							
Alkali reactive	Nil	Nil	Nil	Nil	Nil	Nil	Nil

Base on the properties testing result in Table II, III, and IV, in generally, the testing value of recycle coarse aggregate is also similar with natural coarse aggregate, but in the several value of recycle coarse aggregate is smaller than natural coarse aggregate, except the water absorption. It is caused by mortar that adhere on the surface of natural aggregate and more porous in the mortar. The water content in the recycle coarse aggregate is not available or dry, because the recycle coarse aggregate has been adhered by mortar on the natural coarse aggregate surface that the mortar is very porous and very absorb the water (it can be seen in Table V). Furthermore, the recycle coarse aggregate will be arranged to a good gradation in order to meet the ASTM C-136-95a [3] specification. The arrangement of recycle coarse aggregate aims to meet ASTM C-136-95a [3] specification, because the recycle coarse aggregate diameter must be separated manually that it can be seen in Figure 2. Base on the arrangement of recycle coarse aggregate gradation, the recycle coarse aggregate has to be meet to the ASTM C-136-95a [3]. So, recycle coarse aggregate can replace the natural coarse aggregate, but it has to study more detail to know the characteristic of concrete that is made from recycle coarse aggregate. The arrangement of recycle coarse aggregate can be seen in the Figure 3 and percentage of recycle aggregate is :

a. percentage of particle retention on sieve size 5.0 mm is 60%;
b. percentage of particle retention on sieve size 10.0 mm is 25%;
c. percentage of particle retention on sieve size 14.5 mm is 15%.

The variation of particle size tends to rational. Comparing the mechanical properties of those materials show that the performances of recycle aggregate is lower than the natural aggregate, except the absorption and the abrasion value. It is indicate the existence of thin film covered the aggregate.

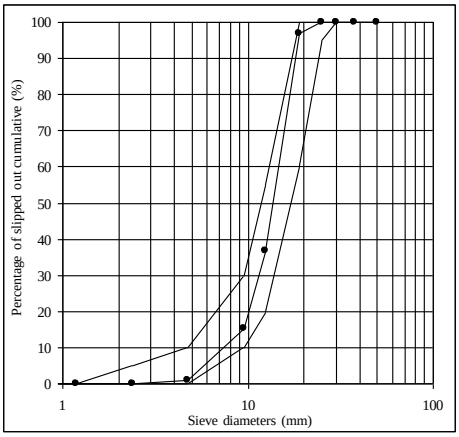

Figure 2. Gradation curve of natural coarse aggregate

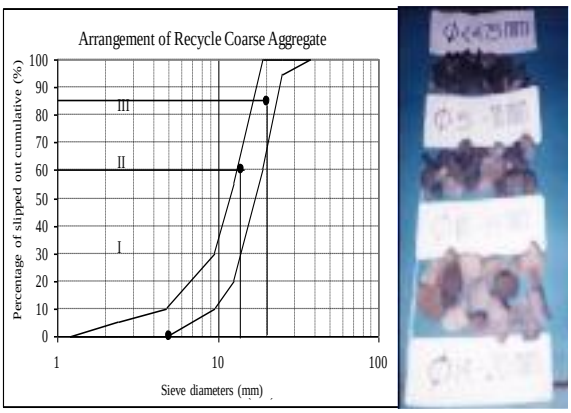

Figure 3. Gradation curve of recycle coarse aggregate and manual separation of particle

Table 5. Mortar content in of coarse aggregate

Type of concrete resources	Mortar content in recycle aggregate (%)			
	diameter < 4.75	diameter 5-14	diameter 10-14	diameter 14-20
Recycle Aggregate w/c 0.7	84.67	45.41	31.89	31.24
Recycle Aggregate w/c 0.6	79.06	37.78	33.85	30.78
Recycle Aggregate w/c 0.5	80.83	38.77	35.30	31.14
Recycle Aggregate w/c 0.4	73.05	39.43	40.71	35.11
Demolish of Ready Mix	84.06	42.94	29.67	24.59
Demolish of burning building	84.80	51.82	25.56	20.54

3. Mix Design Of Concrete

Initial calculation of concrete mix design of natural and recycle concrete aggregate base on ACI 211.1-94 [1] for Normal Strength Concrete (lower than 41 MPa) and ACI 211.4R-93 [2] for high Strength Concrete (above 41 MPa). The variations of composition base material for concrete will be differentiated by water cement ratio and compressive strength of concrete. The variation of water cement ration is 0.4, 0.5, 0.6 and 0.7 and the variation of concrete strength is 25, 30, 40, 50, 65, 70 and 80 MPa. The composition for each concrete mix can be seen in Tabel VI and VII.

Table 6. Composition of concrete mix design base on water cement ratio variation

Specimen code	w/c	Total of Water (kg)	Total of Cement (kg)	Total of Coarse Aggregate (kg)				Total of fine aggregate (kg)	
				Natural	Recycle			Natural	Recycle
					Ø 05-10	Ø 10-14	Ø 14-20		
DUHK-0-100-07	0.70	190.00	271.43	0.00	549.17	205.70	134.84	659.66	0.00
DUHK-100-0-07	0.70	190.00	271.43	958.12	0.00	0.00	0.00	0.00	569.13
DUHK-100-100-07	0.70	190.00	271.43	0.00	549.17	205.70	134.84	0.00	577.22
DUHK-0-50-07	0.70	190.00	271.43	479.06	274.58	51.43	67.42	707.21	0.00
DUHK-50-0-07	0.70	190.00	271.43	958.12	0.00	0.00	0.00	325.20	284.56
DUKH-50-50-07	0.70	190.00	271.43	479.06	274.58	51.43	67.42	353.61	309.42
DUHK-0-100-06	0.60	190.00	316.67	0.00	549.17	205.70	134.84	627.43	0.00
DUHK-100-0-06	0.60	190.00	316.67	958.12	0.00	0.00	0.00	0.00	540.92
DUHK-100-100-06	0.60	190.00	316.67	0.00	549.17	205.70	134.84	0.00	549.02
DUHK-0-50-06	0.60	190.00	316.67	479.06	274.58	51.43	67.42	674.98	0.00
DUHK-50-0-06	0.60	190.00	316.67	958.12	0.00	0.00	0.00	309.09	270.46

Specimen code	w/c	Total of Water (kg)	Total of Cement (kg)	Total of Coarse Aggregate (kg)				Total of fine aggregate (kg)	
				Natural	Recycle			Natural	Recycle
					Ø 05-10	Ø 10-14	Ø 14-20		
DUKH-50-50-06	0.60	190.00	316.67	479.06	274.58	51.43	67.42	337.49	295.31
DUHK-0-100-05	0.50	190.00	380.00	0.00	549.17	205.70	134.84	582.30	0.00
DUHK-100-0-05	0.50	190.00	380.00	958.12	0.00	0.00	0.00	0.00	501.43
DUHK-100-100-05	0.50	190.00	380.00	0.00	549.17	205.70	134.84	0.00	509.53
DUHK-0-50-05	0.50	190.00	380.00	479.06	274.58	51.43	67.42	629.85	0.00
DUHK-50-0-05	0.50	190.00	380.00	958.12	0.00	0.00	0.00	286.52	250.72
DUKH-50-50-05	0.50	190.00	380.00	479.06	274.58	51.43	67.42	314.93	275.57
DUHK-0-100-04	0.40	190.00	475.00	958.12	0.00	0.00	0.00	0.00	442.20
DUHK-100-0-04	0.40	190.00	475.00	0.00	549.17	205.70	134.84	0.00	450.30
DUHK-100-100-04	0.40	190.00	475.00	0.00	549.17	205.70	134.84	514.61	0.00
DUHK-0-50-04	0.40	190.00	475.00	479.06	274.58	51.43	67.42	562.16	0.00
DUHK-50-0-04	0.40	190.00	475.00	958.12	0.00	0.00	0.00	252.68	221.10
DUKH-50-50-04	0.40	190.00	475.00	479.06	274.58	51.43	67.42	281.08	245.95

Specimen code remark :
DU (First and second digit) is Daur Ulang that means Recycle Aggregate
K (third digit) is Kasar that means Recycle Coarse Aggregate
H (Fourth digit) is Halus that means Recycle Fine Aggregate
0 (Fifth digit) is 0 % that means content percentage of Recycle Coarse Aggregate
0 (sixth digit) is 0 % that means content percentage of Recycle Fine Aggregate
04 seventh digit) is water cement ration

table 7. Composition of concrete mix design base on compressive strength of concrete

Specimen code	Total of Water (kg)	Total of Cement (kg)	Total of Natural Fine Ag. (kg)	Total of Recycle Fine Ag. - Burning building (kg)	Total of Recycle Fine Ag.- Demolish Ready Mix (kg)	Total of Natural Coarse Ag. (kg)	**Material**					
							From Burning Building			From Demolish Ready Mix		
							Ø 5 - 10 mm (kg)	Ø 10 - 14 mm (kg)	Ø 14 - 20 mm (kg)	Ø 5 - 10 mm (kg)	Ø 10 - 14 mm (kg)	Ø 14 - 20 mm (kg)
AAHK-100 –100-25	161	333	760	-	-	920	-	-	-	-	-	-
DKHK-0-100-25	217	333	782	-	-	-	507	197	128	-	-	-
DKHK-100-100-25	253	333	-	671	-	-	507	197	128	-	-	-
DRHK-0-100-25	215	333	816	-	-	-	-	-	-	458	208	127
DRHK-100-100-25	273	333	-	720		-	-	-	-	458	208	127
DKHK-50-50-25	253	333	391	336	-	234	144	58	36	-	-	-
DRHK-50-50-25	273	333	408	360		212	-	-	-	131	53	45
AA HK-100 –100-30	195	376	725	-	-	919	-	-	-	-	-	-
DKHK-0-100-30	217	376	782	-	-	-	507	197	128	-	-	-
DKHK-100-100-50	252	376	-	631	-	-	507	197	128	-	-	-
DRHK-0-100-30	215	376	782	-	-	-	-	-	-	458	208	127
DRHK-100-100-30	273	376	-	720		-	-	-	-	458	208	127
DKHK-50-50-30	252	376	391	316	-	233	144	58	36	-	-	-
DRHK-50-50-30	273	376	391	360		211	-	-	-	131	53	45
AAHK-100 –100-40	174	483	638	-	-	920	-	-	-	-	-	-
DKHK-0-100-40	220	483	696	-	-	-	507	197	128	-	-	-
DKHK-100-100-40	251	483	556		-	-	507	197	128	-	-	-
DRHK-0-100-40	218	483	695	-	-	-	-	-	-	458	208	127
DRHK-100-	268	483	-	614		-	-	-	-	45	208	127

Specimen code	Total of Water (kg)	Total of Cement (kg)	Total of Natural Fine Ag. (kg)	Total of Recycle Fine Ag. - Burning building (kg)	Total of Recycle Fine Ag.- Demolish Ready Mix (kg)	. Total of Natural Coarse Ag. (kg)	**Material**					
							From Burning Building			From Demolish Ready Mix		
							Ø 5 - 10 mm (kg)	Ø 10 - 14 mm (kg)	Ø 14 - 20 mm (kg)	Ø 5 - 10 mm (kg)	Ø 10 - 14 mm (kg)	Ø 14 - 20 mm (kg)
100-40										8		
DKHK-50-50-40	251	483	348	278	-	234	144	58	36	-	-	-
DRHK-50-50-40	268	483	348	-	307	212	-	-	-	131	53	45
AAHK-100 - 100-50	163	551	643	-	-	953	-	-	-	-	-	-
DKHK-0-100-50	187	522	597	-	-	-	562	218	141	-	-	-
DKHK-100-100-50	218	522	-	499	-	-	562	218	141	-	-	-
DRHK-0-100-50	183	522	657	-	-	-	-	-	-	507	230	140
DRHK-100-100-50	277	522	-	-	317	-	-	-	-	507	230	140
DKHK-50-50-50	202	522	299	250	-	242	149	60	37	-	-	-
DRHK-50-50-50	230	522	328	-	159	219	-	-	-	136	55	47
AAHK-100 - 100-65	160	563	638	-	-	959	-	-	-	-	-	-
DKHK-0-100-65	160	563	633	-	-	-	619	238	143	-	-	-
DKHK-100-100-65	160	563	-	608	-	-	595	229	138	-	-	-
DRHK-0-100-65	160	563	635	-	-	-	-	-	-	621	239	144
DRHK-100-100-65	160	563	-	-	597		-	-	-	584	225	135
DKHK-50-50-65	160	563	332	302	-	243	150	61	37	-	-	-
DRHK-50-50-65	160	563	326	-	313	220	-	-	-	137	55	47
AAHK-100 - 100-65	156	574	632	-	-	964	-	-	-	-	-	-
DKHK-0-100-70	156	574	628	-	-	-	623	240	145	-	-	-
DKHK-100-	156	574	-	604	-	-	59	231	131	-	-	-

Specimen code	Total of Water (kg)	Total of Cement (kg)	Total of Natural Fine Ag. (kg)	Total of Recycle Fine Ag. - Burning building (kg)	Total of Recycle Fine Ag.- Demolish Ready Mix (kg)	Total of Natural Coarse Ag. (kg)	Material					
							From Burning Building			From Demolish Ready Mix		
							Ø 5 - 10 mm (kg)	Ø 10 - 14 mm (kg)	Ø 14 - 20 mm (kg)	Ø 5 - 10 mm (kg)	Ø 10 - 14 mm (kg)	Ø 14 - 20 mm (kg)
100-70							9					
DRHK-0-100-70	156	574	629	-	-	-	-	-	-	624	240	144
DRHK-100-100-70	156	574	-	-	592	-	-	-	-	588	226	136
DKHK-50-50-70	156	574	332	301	-	245	252	61	37	-	-	-
DRHK-50-50-70	156	574	323	-	310	222	-	-	-	137	55	47
AAHK-100 - 100-80	149	597	621	-	-	976	-	-	-	-	-	-
DKHK-0-100-80	149	567	617	-	-	-	630	243	146	-	-	-
DKHK-100-100-80	149	597	-	594	-	-	605	233	140	-	-	-
DRHK-0-100-80	149	597	618	-	-	-	-	-	-	632	243	146
DRHK-100-100-80	149	597	-	-	583	-	-	-	-	595	229	138
DKHK-50-50-80	149	597	326	296	-	247	153	62	38	-	-	-
DRHK-50-50-80	149	597	318	-	304	224	-	-	-	139	56	48

Specimen code remark :
A or D (First digit) is Alam or Daur Ulang that means Natural or Recycle Aggregate
A or K or R (second digit) is Alam or Kebakaran or ready Mix that means Natural or Recycle Aggregate from Burning Building or Ready Mix Demolish
H (third digit) is Halus that means Recycle Fine Aggregate
K (Fourth digit) is Kasar that means Recycle Coarse Aggregate
0 (Fifth digit) is 0 % that means content percentage of Recycle Fine Aggregate
0 (sixth digit) is 0 % that means content percentage of Recycle Coarse Aggregate
25 (seventh digit) is initial concrete compressive strength deisgn

4. Compressive Test Results And Formula Of Recycled Concrete Aggregate Compressive Strength In Mix Design Analysis

All of the specimen that has been explained on the above chapter will be tested by compressive loading in the UTM (Universal Testing Machine). The model of UTM can be seen in the Figure 4.

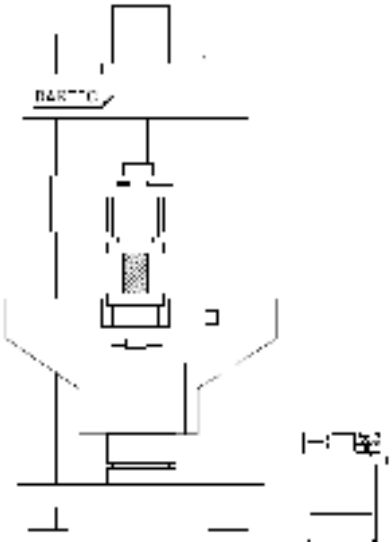

Figure 4. Setup specimen un UTM

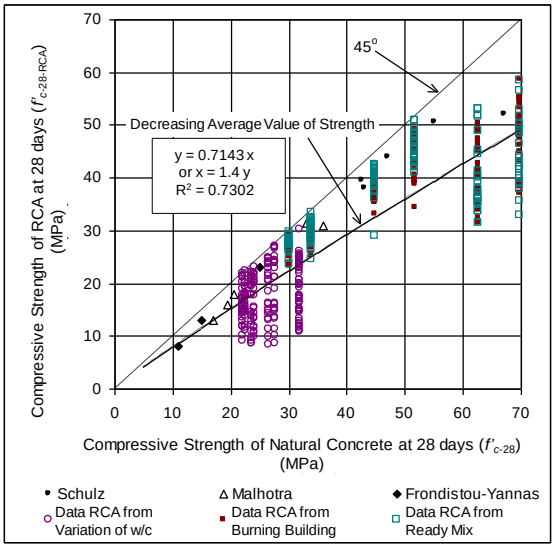

Figure 5. Compressive test result of Natural and Recycle Concrete Aggregate

All of the specimens of concrete have been tested in the 28 days age. The result of compressive loading test will be presented in the curve in Figure 5. Figure 5 illustrate the curve of compressive strength result for several variation of RCA. In the Figure 5, the curve also build line 45 degree to know the correlation of RCA and Natural Concrete and trendline to get average concrete strength correlation between RCA and Natural Aggregate. It aims to know the multiplier factor that will make formula of RCA compressive strength. Base on the compressive test result of Natural and Recycle Concrete Aggregate in Figure 5, the strength of RCA is lower than natural concrete. It is caused by mortar that adhere on the natural aggregate surface and it is also shown in the abrasion test that the percentage value of abrasion is more than natural aggregate. It indicates that the mortar can fall out or flake off from recycle aggregate solidity. It is also represent that recycle aggregate has a lower strength than natural aggregate. So, the concrete that has been made from recycle aggregate has lower strength also than natural concrete. The decreasing of RCA strength is about 20 - 25% for normal concrete strength and 26 to 35 % for high strength concrete. That is shown that the strength decreasing of RCA will be more decreasing for higher concrete strength. It indicates that bonding of aggregate and cement paste is weak, because mortar in the recycle aggregate is easy to fall out. So, the strength of RCA has to increase when design of concrete mixing. It aim to anticipate decreasing of concrete strength.

Furthermore, the compressive strength data of natural and recycle concrete aggregate will been analyzed in order to get a formula of the concrete strength when design for concrete mix or composition of recycle fine and coarse aggregate, cement and water in concrete. Analysis of that formula refers to existing formula that has been written in the ACI 211.1-94 [1] for Normal Strength Concrete (lower than 41 MPa) and ACI 211.4R-93 [2] for high strength concrete. Base on above references, the equation of natural concrete mix design for normal strength concrete is :

$$= \ ' + 1.34 \quad \text{(psi or MPa unit)} \qquad (1)$$

And the equation of natural concrete mix design for high strength concrete is :

$$= \frac{' + 1400}{0.90} \text{ (psi unit)} \qquad (2a)$$

$$= \frac{' + 9.653}{0.90} \text{ (MPa unit)} \qquad (2b)$$

when : f_{cr} is compressive strength initial design to get material composition.

f'_c is compressive strength of concrete at 28 days age.

s_r is planning of deviation standard.

Base on the curve of Compressive Strength result in Figure 5, the formula for RCA mix design will be built in order to meet with requirement and final result of concrete strength. The equation of linear regression in the curve will be substituted to equation (1) and (2). The result of formula is:
The equation of natural concrete mix design for normal strength concrete

$$= 1.4\ ' + 1.34 \quad (\text{psi or MPa unit}) \quad (3)$$

And the equation of natural concrete mix design for high strength concrete is :

$$= 1.4\ (\frac{' + 1400}{0.90})\ (\text{psi unit}) \quad (4a)$$

$$= 1.4\ (\frac{' + 9.653}{0.90})\ (\text{MPa unit}) \quad (4b)$$

Those equation will be use for design of RCA. The multiplier factor of 1.4 in the equation aims to anticipate decreasing concrete strength in RCA when determining of initial concrete strength. Furthermore, design calculation of material composition in RCA is same with ACI 211.1-94 [1] for Normal Strength Concrete (lower than 41 MPa) and ACI 211.4R-93[2] for high strength concrete.

4.1 Aplication Of Rca

In the present, RCA can be used usually for non structural. Type of non structural is curb, concrete brick, rigid pavement, Reinforced Concrete Pipe (RCP), drainage concrete precast, wall panel, etc. Structural application of RCA still needs advance research.

5. Conclusion

The conclusion from the results of experimental testing is :

1) Base on the physically testing, recycle fine and coarse aggregate can replace the natural coarse aggregate.

2) Percentage of water absorption value in Recycle Aggregate is higher that natural aggregate, because cement or paste of cement or mortar that adhere on the surface of sand or natural aggregate and it is also more porous to compare with natural aggregate.

3) Percentage of water content in the recycle fine and coarse aggregate is not available or dry, because the recycle fine and coarse aggregate has been adhered by cement paste or mortar on the natural fine and coarse aggregate surface that the mortar is very porous and very absorb the water.

4) The multiplier factor of 1.4 in the formula aims to anticipate decreasing concrete strength in RCA when determining of initial concrete strength.

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