GLOBAL JOURNAL OF ENGINEERING, DESIGN & TECHNOLOGY
(Published By: Global Institute for Research & Education)
www.gifre.org

TAGUCHI EXPERIMENTAL APPROACH TO LABORATORY EVALUATION OF STATIC MODULUS OF ELASTICITY OF RECYCLED AGGREGATE CONCRETE

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Abstract
This paper looks into the static modulus of elasticity of recycled aggregate concrete using experimental method. Modulus of elasticity plays an important role in the life of concrete structure because it affects the serviceability and structural performance of concrete structure. Taguchi approach was used to prepare the materials and reduce the number of experiments required. Orthogonal array L_{16} (4^5 Series) which has four levels and five factors was used to prepare the mix proportions. The result showed that Optimum conditions for maximum modulus of elasticity were obtained at lower water/cement ratios and recycled aggregates with values ranging between 35.89-41.26 Gpa. The Taguchi experimental approach is a good tool for obtaining optimum conditions in experiment involving many factors.

Keywords- Modulus of Elasticity, Recycled Aggregtaes, Taguchi method.

1. Introduction
The modulus of elasticity of recycled aggregate comcrete is generally lower that the corresponding concrete made with natural aggregates. This is due to the fact that old mortar attached to original concrete in recycled aggregates usually have comparatively low modulus of elasticity (Hansen,1986). Various researchers have carried out extensive works on the modulus of elasticity of recycled aggregate concrete as contained in Akinkurolere 2008, Hansen, 1986 and Rohi 1996. Also, in his work, Frondistou-Yannas (1977) found that the modulus of elasticity for recycled aggregate concretes made with coarse recycled aggregate and natural sand is 33% lower compared to the modulus of elasticity of corresponding control concretes made with natural aggregate. Also, Gerardu and Hendriks (1985) found a maximum of 15% lower modulus of elasticity of recycled aggregate concretes made with coarse recycled aggregate and natural sand compared with corresponding conventional concretes. When the sand was also replaced with crushed concrete fines, a maximum of 40% reduction in modulus of elasticity was observed while Rasheeduzzafar and Khan (1984) found up to 18% lower static modulus of elasticity in recycled aggregate concretes made with coarse recycled aggregate and natural sand compared to the modulus of elasticity of corresponding control concretes made with conventional aggregates**.**

Various methods on how to calculate the modulus of elasticity depending on the concrete strength have been defined by many researchers. Ravindrarajah and Tam (1985) defined some methods for the modulus of recycled aggregate concrete as presented below.

Static Modulus of Elasticity $(E) = 4.63 f_{cy}^{0.5}$ ……………………………………… (1)

$(E) = 7.77\ f_{cu}^{0.33}$ …………………………………….. (2)

f_{cy} and f_{cu} are cylindrical and cubic test on element's compressive strength respectively.

2. Materials and Methods
All The materials used in this research project were typical of those normally used in the commercial production of Portland cement concrete. The materials include Portland cement, fly ash, coarse and fine aggregates. The properties of these materials are described below.

2.1Portland Cement
The cementious materials used for this investigation were Chinese Standards (GB175-1999) ordinary Portland cement P. C 32.5.

2.2 Fly Ash
Class II fly ash classified according to GB/T 1596-2005 was used in this research.

2.3 Coarse Aggregate
A 26.5mm nominal maximum sized crushed limestone was used as coarse aggregate in this research. The specific gravity of the natural coarse aggregates in the saturated dry condition (S.S.D) was 2.71.

2.4 Fine Aggregates
Natural river sand with maximum nominal size of 4.75mm was used. The aggregate was kept in saturated surface dry condition until it was used. The specific gravity of the fine aggregate was 2.60.

2.5 Water
The water used in the mix proportion calculation and for the entire project was regular tap water. The specific weight of water was assumed to be $9.81 kN/m^3$

Taguchi (1988) orthogonal array L_{16} (4^5 Series) which has four levels and five factors was used to prepare the mix proportions. Mixing was conducted under standard laboratory conditions using 100kg capacity concrete mixer in accordance with Chinese code . 150 x 150 x 300 mm prisms specimens were cast (Chinese Standard GBJ81-85) and tested. The orthogonal array L16 (4^5 series) used for the experiment is given in Table 1 with factors assignment while Table 2 presents the summary of the test factors. The proportioning of the materials is presented in Table 3.

Table 1 Orthogonal array L16 (4^5 series) with factors assignment

Test No.	**Factors investigated**				
	W/C[1]	RA[2] (%)	FA[3] (%)	Ignored	
1	0.45	0	0	1	1
2	0.45	30	20	2	2
3	0.45	60	30	3	3
4	0.45	100	40	4	4
5	0.50	0	20	3	2
6	0.50	30	0	4	1
7	0.50	60	40	1	4
8	0.50	100	30	2	3
9	0.55	0	30	4	3
10	0.55	30	40	3	4
11	0.55	60	0	2	1
12	0.55	100	20	1	2
13	0.58	0	40	2	4
14	0.58	30	30	1	3
15	0.58	60	20	4	2
16	0.58	100	0	3	1

1W/C - Water-Cement ratio.
2RA - Recycled aggregates.
3FA-Fly-ash

Table 2. Summary of test factors and their levels for OA L16 (4^5 series)

Level	**Factors**		
	W/C	**RA**	**FA**
1	0.45	0%	0%
2	0.50	30%	20%
3	0.55	60%	30%
4	0.58	100%	40%

Table 3. Sixteen sets of mix proportions of concrete using L16 (4^5 series) orthogonal array

Test No.	**W/C**	**RA (kg/m^3)**	**Fly ash (kg/m^3)**	**NA[4] (kg/m^3)**	**Water (kg/m^3)**	**Cement (kg/m^3)**	**Sand (kg/m^3)**
1	0.45	0	0	1160	149	330	660
2	0.45	335	66	812	149	264	660
3	0.45	812	99	464	149	231	660
4	0.45	1117	132	0	149	198	660
5	0.50	0	66	1160	165	264	660
6	0.50	335	0	812	165	330	660
7	0.50	812	132	464	165	198	660
8	0.50	1117	99	0	165	231	660
9	0.55	0	99	1160	182	231	660
10	0.55	335	132	812	182	198	660
11	0.55	812	0	464	182	330	660
12	0.55	1117	66	0	182	264	660
13	0.58	0	132	1160	191	198	660
14	0.58	335	99	812	191	231	660
15	0.58	812	66	464	191	264	660
16	0.58	1117	0	0	191	330	660

4NA- natural aggregates

The elastic modulus (Young Modulus) test was performed in accordance with GB/T 50081 (2002). A compressometer was used to measure the deformation of the specimen. The Elastic modulus was then calculated from the stress-strain plot according to the following equation:

$E_c = F_a - F_0 / (E_2 - 0.00005)$……………………………………………………..…………… (3)

Where:

E_c = chord modulus of elasticity in Mpa

F_a = stress corresponding to 1/3 of ultimate load.

F_0 = stress corresponding to strain of 0.00050

E_2 = longitudinal strain by stress F_a

The tests were determined using a compression machine with a loading capacity of 2000 KN. Figure 1 shows the set-up for the test.

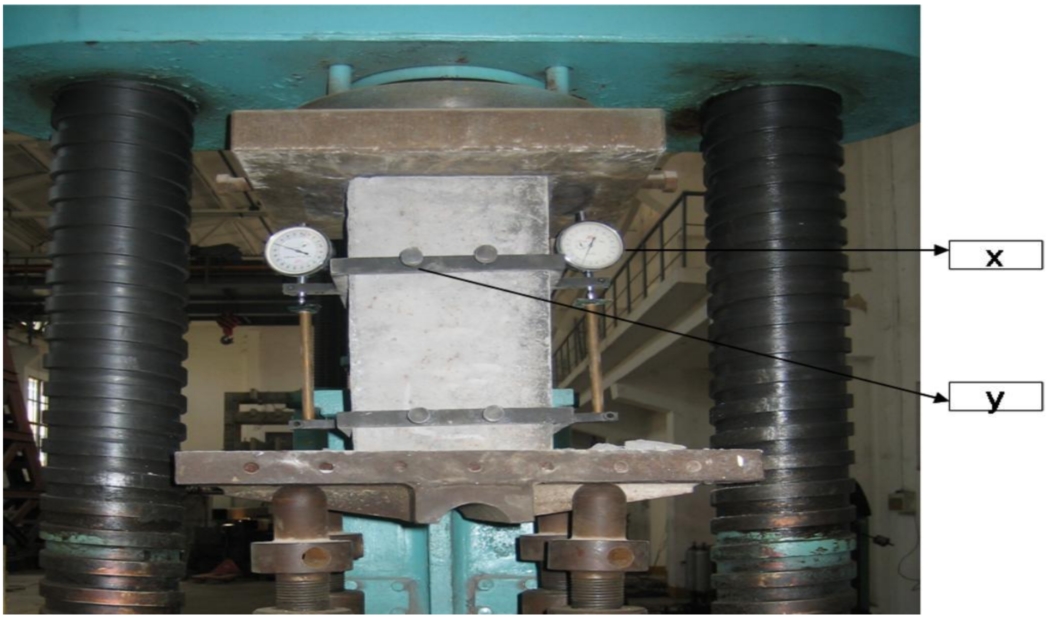

Figure 1. Test set up for static elastic modulus of elasticity (x = Compressometer, y = Testing ring)

3. Results and Discussion

Modulus of elasticity results are presented in Tables 4 to 6. As can be seen from Table 4, the rate of strength development was relatively higher at lower water-cement ratios and it also decreased with an increase in recycled aggregate contents. This reduction might be due to old mortar with a comparatively low modulus of elasticity, which was attached to the recycled aggregates which also conform to reports as contained in Hansen, 1986. Addition of fly-ash gave little improvement but not significant. Lower values for modulus of elasticity can cause higher deflection of structures made of recycled aggregates. However, for structures where deflection in not a significant problem, this disadvantage may not be significant. The result is in conformity with previous works done by Frondistou-Yannas (1977), Gerardu and Hendriks (1985) and Rasheeduzzafar and Khan (1984)

The S/N ratios and orthogonal analysis follow the same trend with what has been discussed earlier. However, in the analysis of variance the most significant factor at later ages (28 and 90 days) was just the water-cement ratio while other factors at these ages were categorized as not very significant.

Table 4. L16 (4^5 Series) orthogonal arrays used and test results for modulus of elasticity strength

Test No.	Average modulus of elasticity strength E_c(Gpa)			% Strength increment		S/N ratio for average modulus of elasticity		
	7-Day	28-Day	90-Day	7-28 Days	28-90 Days	7-Day	28-Day	90-Day
1	27.85	34.01	41.26	22.12	21.32	28.9	30.63	32.31
2	25.35	28.20	39.37	11.24	39.61	28.07	29.00	31.90
3	25.01	25.74	35.89	2.92	39.43	27.94	28.21	31.10
4	23.34	24.76	34.67	6.08	40.02	27.36	27.87	30.80
5	24.22	25.14	34.82	3.8	38.5	27.68	28.01	30.84
6	24.54	24.70	34.16	0.65	38.3	27.79	27.85	30.67
7	23.53	24.66	33.98	4.8	37.79	27.43	27.84	30.62
8	22.28	21.53	30.08	-3.37	39.71	26.96	26.66	29.55
9	22.73	21.27	28.65	-6.42	34.7	27.13	26.55	29.14
10	21.96	20.83	28.13	-5.15	35.05	26.82	26.37	28.98
11	21.37	20.78	28.11	-2.76	35.27	26.59	26.34	28.98
12	20.21	20.09	27.82	-0.59	38.48	26.1	26.06	28.89
13	21.01	20.22	27.46	-3.76	35.81	26.45	26.11	28.77
14	19.27	20.19	27.10	4.77	34.22	25.69	26.10	28.65
15	19.27	20.18	25.36	4.72	25.67	25.69	26.08	28.08
16	18.33	20.10	24.00	9.66	19.4	25.25	26.06	27.60

Table 5. Analysis of variance (ANOVA) for modulus of elasticity

	Factor	DOF	SS	Contribution factors of SS (%)	F ratio	Prob >F
7-Day	W/C	3	78.72	79.29	94.76	<.0001*
	RA	3	17.47	17.60	21.02	0.0014*
	FA	3	1.43	1.44	1.73	0.2608
	Error	6	1.66	1.67	Prob >F	-
	Total	**15**	**99.28**	**100**	-	**0.0001***
28-Day	W/C	3	162.44	72.82	18.59	<.0019*
	RA	3	26.08	11.69	2.98	0.1180
	FA	3	17.09	7.66	1.96	0.2221
	Error	6	17.47	7.83	Prob >F	-
	Total	**15**	**223.08**	**100**	-	**<.0001***
90-Day	W/C	3	336.38	87.08	73.32	<.0001*
	RA	3	34.93	9.04	7.61	0.0181
	FA	3	5.79	1.50	1.26	0.3686
	Error	6	9.18	2.38	Prob >F	-
	Total	**15**	**386.28**	**100**	-	**<.0003***

Table 6. L16 (4^5 Series) orthogonal analysis for modulus of elasticity

	Factors	E1	E2	E3	E4	R
7- Day modulus of elasticity E_c(Mpa)	W/C	25.39	23.64	21.57	19.47	5.92
	RA	23.95	22.78	22.29	21.04	2.91
	FA	23.02	22.26	22.32	22.46	0.76
28- Day modulus of elasticity E_c(Gpa)	W/C	28.18	24.01	20.74	20.17	8.01
	RA	25.16	23.48	22.84	21.62	3.54
	FA	24.90	23.40	22.18	22.62	2.28
90-Day modulus of elasticity E_c(Gpa)	W/C	37.80	33.26	28.18	25.98	11.82
	RA	33.05	32.19	30.83	29.14	3.91
	FA	31.88	31.84	30.43	31.06	1.45

4. Conclusions

The modulus of elasticity of recycled aggregates concrete from the results is generally lower when compared with conventional concrete; however addition of fly-ash gave a little improvement on the tested properties although not significant. Taguchi method is a good tool in evaluation properties of concrete involving many factors and number of experiments.

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