

# MECHANICAL PROPERTIES OF REINFORCED CONCRETE BEAM WITH RECYCLED COARSE AGGREGATES

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## ABSTRACT

*The significant increment of waste concrete in recent years that is happening worldwide has a tremendous consequence to the environment. Recycling concrete wastes will reduce the amount of waste as well as save natural resources, thus help promote green and sustainable development. This study presents an experimental investigation dealing with the development of green concrete using recycled concrete waste (RCWA) as coarse aggregate replacement materials. The mechanical properties of reinforced concrete (RC) beams in terms of its compressive and flexural strengths were determined. The main parameter considered is the percentage of RCWA in the concrete design of RC beams that ranges from 0% to 50%. From the test results, it was observed that the flexural strength and the compression strength decreased as the percentage of recycled concrete waste aggregate used increased. Generally, the flexural strength of RC beam with RCWA can be 5% to 12.4% lower than that of conventional concrete made with natural course aggregate.*

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**Keywords:** Recycle concrete waste aggregate, flexural strength, reinforced concrete beam, deflection, green concrete

## INTRODUCTION

Johnston, Dawson, & Brown (1998) reported that about 12 million tonnes of concrete waste are generated in the United Kingdom (UK) each year. In Malaysia, 9.3 million tonnes of concrete waste are generated each year (Saadi, Ismail, & Alias, 2016). This problem is the result of the increasing amount of wastes concrete from the demolition of old buildings, debris from construction industry or natural disaster that caused large amount of concrete rubbles. This significant increase of waste concrete affects the environment which leads to the use of large landfill space.

The environmental and societal impact due to the production of waste concrete is rather alarming and is a growing concern all over the world which calls for immediate action. Recycling waste concrete as aggregate is one of the best potential solution to be considered. Previous studies have proven that concrete waste could be utilized not only as recycled aggregate for production of environmental friendly concrete, but also for a lot of other applications in construction with considerable advantages (Malesev et. al., 2010; Corinaldesi et. al., 2011; Ajdukiewicz and Kliszewicz, 2006; Lakshmi and Nivedhitha, 2015). Some of the advantages include lower environmental pollution and reduction in valuable landfill space, thus encouraging a green city environment. Besides that, the massive quantity of natural aggregates resources being harvested resulting from the high demand in the construction industry could be reduced, thus savings in natural aggregate resources could be promoted.

There are several developed countries that are producing and utilizing recycled aggregate in construction industries like USA, Australia, Germany and Japan (Neeraj, Mridul, & Minocha, 2015). The European Aggregates Association, Annual Review report, (2012) revealed that Germany is the greatest producer of recycled aggregate, with a production of about 60 million tonnes followed by UK, Netherlands, and France with about 49, 20, and 17 million tonnes, respectively. Structural design requires waste concrete to be crushed into the required sizes of aggregates.

Previous reported studies (Poon et al, 2004; Lakshmi & Nivedhitha, 2015) confirm that concrete with recycle concrete wastes aggregates up to 20% can be used without compromising the concrete strength. Optimum replacement of natural aggregates with recycled aggregates was found

to be between 10% - 20%. Recycled coarse aggregate concrete increases in the ratio of compressive strength as the water-cement ratio decreased. Recycled concrete aggregates produced a lower strength compared to natural aggregates. Young's modulus for the recycled aggregate concrete were shown to be 5% to 20% lower than the natural aggregate concrete. For the recycled fine aggregate concrete, compressive strength decreased as the replacement ratio of recycled fine aggregate increased. Higher compressive strength was obtained for 5 mm recycled fine aggregate compared with 20 mm size of aggregate (Kikuchi et. al., 2015). Lower compressive strength of concrete with recycled waste concrete aggregates is obtained due to a higher water absorption capacity and the existence of a wide range of density variation in the recycled aggregates (Barra, 1998; Kikuchi et. al., 2015).

The available studies on the compression strength and other properties of recycle concrete are abundant, however studies on flexural strength of concrete with recycle concrete waste aggregates are still limited especially on the flexural strength of reinforced concrete beam with recycle concrete aggregates. Malešev, Radonjanin, & Marinković, (2010) have proven that regardless of the replacement ratio, recycled aggregate concrete in reinforced concrete beam, had a satisfactory performance, provided, quality recycled concrete coarse aggregate is used. However, the feasibility of utilizing concrete debris after recycling in the construction industry reinforced concrete beam has yet to be explored.

In this paper, a series of laboratory tests were carried out to determine the compression strength of concrete cube and the flexural strength of reinforced concrete beam containing recycled concrete waste aggregates from laboratory concrete debris. The results were then compared with conventional concrete containing natural coarse and fine aggregates.

## **EXPERIMENTAL PROGRAM**

Experimental program was conducted on concrete cubes and reinforced concrete beam specimens with RCWA as partial replacement of course aggregate. The details of the specimens are presented in Table 1. The specimens were labelled according to the percentage of RCWA used, namely 0%RCWA, 25%RCWA and 50%RCWA for 0%, 25% and 50% of RCWA respectively. A total of six (6) 150 mm x 150 mm x 750 mm RC beams

specimens and twenty-seven (27) 150 mm x 150 mm x 150 mm concrete cube specimens were prepared. Two beam specimens were prepared for each different proportion of RCWA namely, 0%, 25% and 50% respectively. The beam specimens were designed as a simply supported beam with concrete characteristic strength of Grade C30, in accordance to Eurocode 2. The diameter for the longitudinal reinforcement bars and links are 10 mm and 6 mm respectively, while the diameter of the hanger bars used is 8mm.

**Table 1: Specimens Details**

Specimens Designation	Concrete Cube		Beam			
	No. of Spec.	Size (mm <sup>3</sup> )	No of Spec.	Size (b mm x h mm x L mm)	Main Reinforcement	Links
0% RCWA	9	150 x 150 x 150	2	150 x 150 x 750	4R10	R6
25% RCWA	9	150 x 150 x 150	2	150 x 150 x 750	4R10	R6
50% RCWA	9	150 x 150 x 150	2	150 x 150 x 750	4R10	R6

### Recycled Concrete Aggregates

The waste concrete was obtained from the disposal area at Heavy Structural Laboratory, Faculty of Civil Engineering in UiTM Pulau Pinang. The nominal sizes of the natural and recycle concrete aggregates used are 10mm and 20mm. The RCWA were prepared by crushing the concrete wastes manually using a hammer, into smaller pieces. The crushed pieces were then sieved and aggregates retained on sieve size 10 and 20 mm were collected. A partial replacement aggregate from recycle concrete waste used was 25% and 50% for both the 10mm and 20mm course aggregate size. Since the recycle concrete aggregates have high water absorption capacity, the aggregates are maintained at dry surface conditions before mixing.

### Concrete Mix Proportions

The concrete mix proportions of grade C30 were designed to achieve the target strength of 30 MPa. Three different concrete mixes were used in the experimental program of this study. All different mixes were designed with 0.5 water cement ratio. The detail of the mix proportion is tabulated in Table 2. The proportions of the concrete mixes are given for quantities per cubic meter. The quantities of the RCWA for size 10 mm and 20 mm differ for each type of concrete mixes.

The mixing procedure adopted in this study is similar to the procedure described by Neeraj, Mridul & Minocha, (2015). First, both coarse and fine aggregates were added in a rotating mixing drum and dry mixed for 30 seconds, so that all the aggregates could mix homogenously. Then, the first half portion of the mixing water was added into the mixer and the mixing continued for another 2 min. To facilitate the absorption of water into aggregates, the mixer was stopped for 3 min. After that, the cement was added and the mixer continued for another 30 seconds. The remaining half of the mixing water was finally added and mixing continued for approximately 2 min more. The mixing procedure and time have been kept constant for all the mixes.

Before the concrete casting, the workability of the fresh concrete mix was determined by conducting a slump cone test according to the BS EN 12350-2-2000. The average concrete slump obtained was 35 mm, 32 mm and 30 mm for RCWA contents of 0%, 25% and 50% respectively. It was classified as a true slump where the concrete was simply subsided and keeping more shape of slump cone.

The casting of cubes and beams was carried out as per mix proportion shown in Table 2 in laboratory condition. The concrete mixes were poured into steel beam and cube moulds, and then compacted to remove any air void trapped inside the mould. The hardened concrete specimens were demoulded at 24 hours after casting and then the specimens were immersed in water for curing for 28 days.

**Table 2: Proportion of Concrete Mixes**

Quantities Per m <sup>3</sup>	Cement (kg)	Water (kg)	Fine Aggregates (kg)	Natural course aggregate (kg)		RCWA (kg)		Ave. Slump (mm)
				10 mm	20 mm	10 mm	20 mm	
0% RCWA	360	180	819.2	362	724	-	-	35
25% RCWA	360	180	819.2	271.5	543	90.5	181	32
50% RCWA	360	180	819.2	181	362	181	362	30

## Specimens and Esting

The mechanical properties in terms of the compressive strength and flexural strength were determined. Concrete cubes were tested using compressive test machine as per procedure based on BS 1881:118:198. The compressive strength was determined on the 3rd, 7th and 28th day curing period of the concrete cube specimens, while the flexural test on beam specimens at 28-day curing period. The beam specimens were tested using the 1000 kN universal testing machine (UTM) for three points bending test according to BS 1881:118:1983. The beam specimens were placed on the two supporting rollers. The support was located 50 mm from the end span of the beam. Distance,  $L$  between two supports is 700 mm centre to centre. A linear variable differential transformer (LVDT) was used to measure the displacement at the middle span of the beam. The schematic drawing and the actual three bending test set-up is shown in Figure 1.

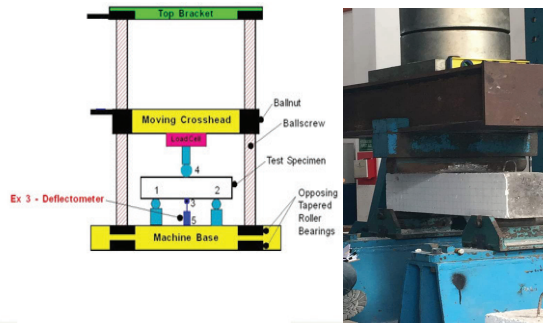


Figure 1: Flexural Test Set-up

## RESULTS AND DISCUSSIONS

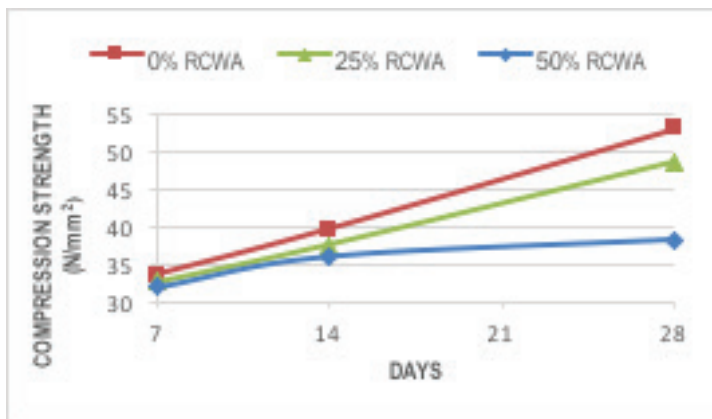
Results of the compression test conducted on concrete cubes after 7 days, 14 days, and 28 days of curing is presented in Table 3. The graphical representation of the effect of RCWA on compressive strength of concrete with different concrete mixes is shown in Figure 2.

Result shows that the compressive strength of the specimens decreases with the increase of RCWA. Significant decrement of the compression

strength occurred on the 28th day for specimen 50%RCWA. The decrement of 25%RCWA and 50%RCWA on the 28th days are recorded to be 8.7% and 28.2% respectively.

**Table 2: Compressive Strength of Concrete with RCWA**

Specimen Designation	Curing Days	compressive strength (kN/mm <sup>2</sup> )	% different
0%RCWA	7	33.45	-
25%RCWA		32.55	2.7
50%RCWA		31.92	4.6
0%RCWA	14	39.62	-
25%RCWA		37.55	5.2
50%RCWA		35.92	9.3
0%RCWA	28	53.09	-
25%RCWA		48.49	8.7
50%RCWA		38.13	28.2



**Figure 2: Effect of RCWA on Compressive Strength of Concrete**

From the observed results, it can be concluded that, concrete with 25% replacement of natural aggregates with recycle concrete aggregates, was found to be good in compression. However, the compressive strength for specimens 50%RCWA showed a significant drop compared to the control specimens. Nevertheless, the compressive strength obtained for specimen with 50% replacement of natural aggregates with recycle concrete aggregates, is still acceptable as the target strength of 30 MPa is found to

be achievable. These observations exhibit a similar trend as the previous findings reported in the literature (Muthu Lakshmi and Nivedhitha, 2015). Thus in compression members like concrete blocks, concrete pavements etc. RCWA up to 25% can be used without compromising on strength. In minor infrastructures works like foot paths, gutters, paving blocks etc., RCWA with 50% replacement or more can be used, thus it is more economical.

### Flexural Strength

The flexural strength of the reinforced concrete beams with RCWA after 28 days of curing was determined from a three-point bending test. Results of the flexural strength of six RC beam specimens are presented in Table 4. Experimental result shows that the flexural strength of RC beams with RCWA decreases as the percentage of RCWA content increases. The decrement of flexural strength of specimens 25%RCWA and 50%RCWA were recorded to be 5.04% and 12.46% respectively compared to the control specimens 0%RCWA.

**Table 3: Flexural Test Strength of RC Beam with RCWA**

Specimen Designation	Average Deformation (mm)	Average Maximum Load (kN)	Average Flexural strength (N/mm <sup>2</sup> )	Reduction Performance (%)
0%RCWA	3.37	60.73	20.23	-
25%RCWA	3.73	57.62	19.21	5.04
50%RCWA	6.84	53.12	17.71	12.46

The load-deflection curve for different percentage of RCWA from the three points bending test is shown in Figure 3. In general, all the specimens exhibit similar load deflection response. However, it was observed that the middle span deflection of the beam increased with increasing RCWA content. The displacement at maximum load is recorded to be 3.37 mm, of 3.73 mm and 6.84 mm for beam specimens of 0%RCWA, 25%RCWA and 50%RCWA respectively. This observation is similar to the findings reported by Mcneil & Kang, (2013), and Malesev et al. (2010), which explained that the increased deflection in RCWA RC beams is likely due to the reduced Modulus of Elasticity of the concrete. Low Modulus of Elasticity indicated



by the higher mid-span deflection, thus easier to deform compared to the RC beams with natural aggregates.

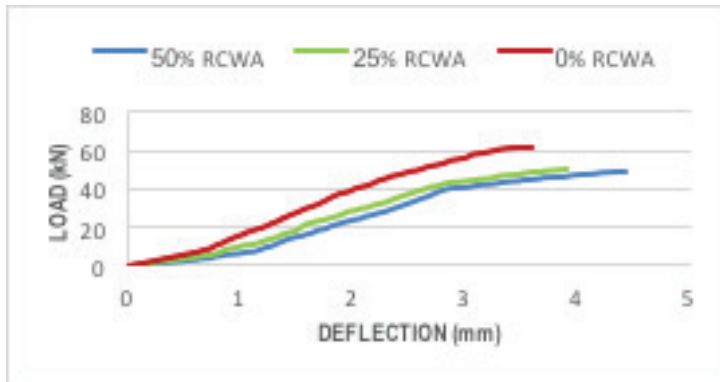


Figure 3: Load-deflection Curves of RC Beam with Different Percentage of RCWA

### Crack Behaviour

The crack behaviour of the beam specimens with different percentage of RCWA is shown in Figure 4. The crack propagation behaviour of the beam specimens was observed throughout the three points bending test. In general, all the specimens exhibit similar crack behaviour. However, it was observed that the beam specimens fractured either due to bending or a combination of bending and shear.



Figure 4: The Effect of RCWA to the Beams Deflection Behaviour

For the specimen with 0%RCWA, the crack was initiated at mid-span of the beam soon after the maximum load was reached. The cracks then propagated vertically to the top towards the point where the load was being applied. After that, it propagated almost diagonally to both supports where the load progress to ultimate load until fracture. The beam failed due to bending since the beam fractured at mid span.

For beam specimens of 25%RCWA and 50%RCWA, the crack pattern started at mid-span of the beam soon after the yield load was reached. The crack then propagated to the top of the beam where loading was applied. After that, the crack propagated to the support where the load progress to ultimate load until fracture. The beams failed due to the combination of bending and shear since the beam fractured at the edge supports.

Based on the observation of service load deflection, RC beam specimens with RCWA performed less well than the specimens with natural aggregates. The increased deflection in RCWA RC beams is likely due to the reduced Modulus of Elasticity of the concrete. Low Modulus of Elasticity indicated by the higher mid-span deflection, thus easier to deform compared to the RC beams with natural aggregates. These behaviours are similar to the observation reported by Mcneil & Kang, (2013).

## **CONCLUSION**

This study presents an experimental investigation dealing with the development of green concrete using recycled concrete waste (RCWA) as coarse aggregate replacement materials. Laboratory tests were carried out to determine the concrete compression strength of concrete cube and the flexural strength of reinforced concrete beam containing recycled concrete aggregates (RCWA) from laboratory concrete debris. The results were then compared with conventional concrete containing natural coarse and fine aggregates.

In general, the compressive strength of concrete cubes decreases with the increasing contents of RCWA. The decrement of the compression strength for specimen 25%RCWA and 50%RCWA on the 28th day are recorded to be 8.7% and 28.2% respectively. The specimen with 25% RCWA, achieved a compression strength that is above the mean target strength of 43.12 N/mm<sup>2</sup>. While, the compressive strength obtained for specimen with 50% RCWA, is still acceptable as the designed strength of 30 MPa is found to be achievable. Thus, in compression members like concrete blocks, concrete pavements etc., RCWA up to 25% can be used without compromising on strength. Meanwhile, RCWA with 50% replacement or more can be used in minor infrastructures works like foot paths, gutters, paving blocks etc., thus more economical.

The flexural strength of RC beams with RCWA was found to be decreasing as the percentage of RCWA content increases. The decrement of flexural strength of specimens 25%RCWA and 50%RCWA were recorded to be 5.04% and 12.46% respectively compared to the control specimens 0%RCWA. In general, it was observed that the middle span deflection of the beam increased with increasing RCWA content. The displacement at maximum load is recorded to be 3.37 mm, of 3.73 mm and 6.84 mm for beam specimens of 0%RCWA, 25%RCWA and 50%RCWA respectively. The increased deflection in RCWA RC beams is likely due to the reduced Modulus of Elasticity of the concrete. It was also observed that beam specimens with RCWA fractured either due to bending or a combination of bending and shear.

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