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Recycling of Brick Aggregate Concrete: Physical and Mechanical Properties

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ABSTRACT

A detailed investigation was conducted for recycling of demolished concrete as coarse aggregate for new constructions works. For this, demolished concrete blocks from 33 different building sites were collected and broken into pieces as coarse aggregate for investigations. In Bangladesh, in most of the old structures, brick chips were used as coarse aggregate. Therefore, the recycled aggregate investigated in this study are different than the recycled aggregate investigated in other countries which are made of stone chips. The properties of recycled aggregate, such as specific gravity, absorption capacity, and abrasion were tested. More than 700 cylinder concrete specimens of diameter 150 mm and height 300 mm were made with W/C =0.45 and 0.55. Concrete specimens were tested at 7, 14, and 28 days for compressive strength, tensile strength, stress-strain curve, and Young's modulus. The results are compared with virgin brick aggregate of different quality.

Based on this investigation, it is revealed that recycled aggregate can be used as coarse aggregate for making concrete of strength 20.7 to 31.0 MPa. For the same mix design, the recycled aggregate concrete produces almost similar strength compared to the virgin brick aggregate concrete commonly used in Bangladesh. However, relatively better performance of recycled aggregate concrete is found for W/C = 0.45.

Keywords: Brick, Compressive Strength, Concrete, Recycling, Strain, Tensile Strength.

INTRODUCTION

Concrete consumption in the world is estimated at two and a half tons per capita per year (equivalent to 17.5 billion tons for 7 billion population in the world) (CAMBUREAU, 2008; Mehta, 2009). To make this huge volume of concrete 2.62 billion tons of cement, 13.12 billion tons of aggregate, 1.75 billion tons of water are necessary. Generally, aggregates are collected by cutting mountains or breaking river gravels or boulders, or by breaking clay bricks. A significant amount of natural resource can be saved if the demolished concrete is recycled for new constructions. In addition to the saving of natural resources, recycling of demolished concrete will also provide other benefits, such as creation of additional business opportunities, saving cost of disposal, saving money for local government and other purchaser, helping local government to meet the goal of reducing disposal, etc. At present, the amount of global demolished concrete is estimated at 2~3 billion tons (Torring and Lauritzen, 2002). Sixty to seventy percent of demolished concrete is used as sub-base aggregate for road construction (Yanagibashi et al, 2002). By recycling of demolished concrete, 20% of normal aggregates can be saved. It is also estimated that in the next ten years, the amount of demolished concrete will be increased to 7.5~12.5 billion tons (Torring and Lauritzen, 2002). If technology and public acceptance of using recycled aggregate are developed, there will be no requirement for normal aggregate, if 100% of demolished concrete is recycled for new construction.

In Bangladesh, the volume of demolished concrete is increasing due to the deterioration of concrete structures as well as the replacement of many low-rise buildings by relatively high-rise buildings due to the booming of real estate business. Disposal of the demolished concrete is becoming a great concern to the developers of the buildings. If the demolished concrete is used for new construction, the disposal problem will be solved, the demand for new aggregates will be reduced, and finally consumption of the natural resources for making aggregate will be reduced. In some project sites, it was also found that a portion of the demolished concrete is used as aggregate in foundation works without any research on the recycled aggregates. In most of the old buildings, brick chips were used as coarse aggregate of concrete. Studies related to the recycling of demolished concrete are generally found for stone chips made concrete (Zega et al, 2010; Kou et al, 2011). Therefore, investigations on recycling of brick made demolished concrete are necessary. With this background, this study was planned.

Demolished concrete from demolished building sites were collected and broken into pieces as coarse aggregates. Before making concrete, the aggregates were investigated for absorption capacity, unit weight, and abrasion. Standard grading of the aggregates were controlled. Cylinder concrete specimens of diameter 150 mm and height 300 mm were made and tested for compressive strength, Young's modulus, and stress-strain curves. The results were compared with brick aggregate concrete.

EXPERIMENTAL METHODS

Demolished concrete blocks were collected from the structural members of the demolished buildings. The collected concrete samples were broken into pieces manually in three particular sizes as 25 mm to 20 mm, 20 mm to 10 mm, and 10 mm to 5 mm. Demolished concrete blocks and recycled aggregates are shown in Figure 1. After breaking into pieces, the aggregates were mixed as 5% from 25 mm to 20 mm, 57.5% from 20 mm to 10 mm, and 37.5% from 10 mm to 5 mm as per ASTM C33-93. The aggregates were tested for absorption capacity, specific gravity, unit weight, and abrasion. The specific gravity and absorption capacity are determined as per ASTM C128, unit weight as per ASTM C29, and abrasion value as per ASTM C131. As a control case, first class brick aggregates were used. Some cylinder specimens (made with brick chips) were also made in the lab and then broken into pieces for recycling. These are the one-year old recycled brick aggregates. The FM, water absorption and specific gravity of sand used in this investigation were 2.64, 3.9%, and 2.61, respectively. After investigation of aggregates, concrete cylinders of size 150 mm in diameter and 300 mm in height were made for evaluation of compressive strength at 7, 14, and 28 days as per ASTM C39. The investigated cases are summarized in Table 1. The mixture proportions of concrete for all cases are summarized in Table 2. Sixty four cases were investigated. W/C ratios of concrete were 0.55 and 0.45. Cement content of concrete was 340 kg/m^3 for all cases. Sand to total aggregate volume ratio was 0.44. Naphthalene based superplasticizer was used for W/C=0.45 to improve the workability of concrete. Total mixing time of concrete was controlled at 5.5 minutes. After mixing concrete, the workability of concrete was measured by slump cone test. Cylinder concrete specimens were made and demolded after one day of casting. Then the specimens were cured under wet jute bags continuously. The compressive strength of concrete was measured at 7, 14, and 28 days by using Universal Testing Machine (UTM). The strain of concrete specimens was measured by a strain measurement setup with two dial gauges. The gauge length was 100 mm. The failure surfaces of concrete were also checked carefully after crushing of the concrete cylinders. The Young's modulus of concrete was determined from the stress-strain curves. The stress of concrete at strain level 0.0005 was used to determine the Young's modulus of concrete. About 700 concrete cylinders were investigated for 64 cases as summarized in Table 1. For comparison with recycled brick aggregate (RB), picked brick aggregate (PB, which has better quality than other brick aggregates), first class brick aggregate (FB, which is better than second class and third class brick aggregates and it is commonly used in Bangladesh), second class brick aggregate (SB, which is better than third class brick aggregates), and third class brick aggregate (TB) were investigated.

Figure 1. Demolished concrete block and recycled aggregates

RESULTS AND DISCUSSIONS

Properties of Aggregates Investigated

The properties of recycled aggregates investigated are summarized in Table 3. For comparison, brick aggregates were also investigated. One-year old aggregates were obtained by crushing the cylinder specimens tested at the laboratory. In addition to the one- year old recycled aggregates, recycled aggregates from 15, 20, 28, 29, 30, 31, 32, 33, 35, 38, 43, 45, 46, 50, 52, 55, and 60 years old buildings were also investigated. The concrete of these buildings was made by brick chips. In most of the cases, the absorption capacity of the recycled aggregates is lower than the first class brick aggregates. Also, in most of the cases, no significant difference is found between the abrasion values of first class brick aggregate and recycled brick aggregate. From the properties of brick and recycled brick aggregate, it is understood that recycled brick aggregate is better or similar to the brick aggregate commonly used in Bangladesh.

Table 1. Cases Investigated (64 Cases)

Case No.	Symbol	Explanation
1 ~ 29 (W/C=0.55)	PBWC55, FBWC55, SBWC55, TBWC55, RBY1WC55, RBY1.5WC55, RBY15WC55, RBY28WC55, RBY29WC55, RBY30WC55, RB31WC55, RBY32WC55, RBY33WC55, RBY34WC55, RBY35aWC55, RBY35bWC55, RBY35cWC55, RBY36WC55, RBY37aWC55, RBY37bWC55, RBY38aWC55, RBY38bWC55, RBY40WC55, RBY41WC55, RBY43WC55, RBY44WC55, RBY45WC55, RBY46WC55, RB60WC55.	PB – Picked Brick Aggregate, FB–First Class Brick Aggregate, SB– Second Class Brick Aggregate, TB– Third Class Brick Aggregate, The digit after PB, FB, SB, and TB indicates W/C. RB – Recycled Brick Aggregate, The digit after RB indicates age and the digit after the age indicates W/C. To separate the cases made with recycled aggregate of same ages a, b, c or d are used accordingly.
30 ~ 64 (W/C=0.45)	PBWC45, FBWC45, SBWC45, TBWC45, RBY1WC45, RBY1.5WC45, RBY20WC45, RBY28WC45, RBY29WC45, RBY30WC45, RBY31WC45, RBY32WC45, RBY33WC45, RBY34WC45, RBY35aWC45, RBY35bWC45, RBY35cWC45, RBY35cWC45, RBY35dWC45, RBY36WC45, RBY37aWC45, RBY37bWC45, RBY38aWC45, RBY38bWC45, RBY40WC45, RBY41WC45, RBY43WC45, RBY44WC45, RBY45aWC45, RBY45bWC45, RBY46WC45, RBY50WC45, RBY52WC45, RBY55WC45, RBY60WC45.	

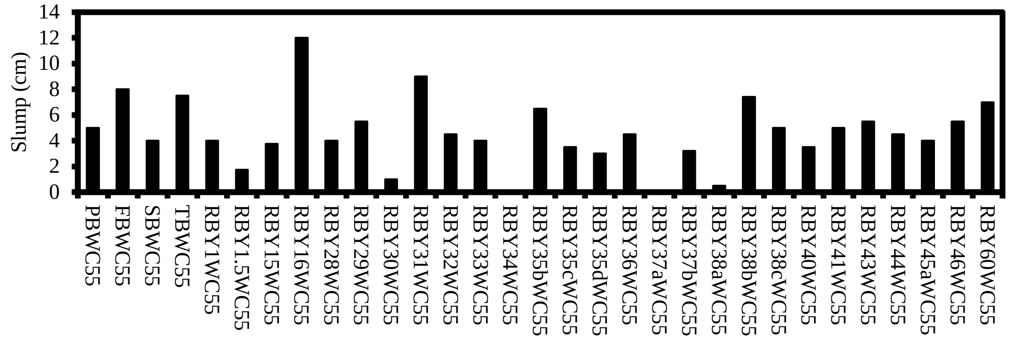
Table 2. Mixture Proportions of Concrete (64 Cases)

CASE (W/C=0.55)	Unit Content (kg/m^3)					CASE (W/C=0.45)	Unit Content (kg/m^3)				
	C	FA	CA	W	AD		C	FA	CA	W	AD
PBWC55	340	782	764	187	-	FBWC45	340	827	884	153	3.06
FBWC55	340	788	842	187	-	SBWC45	340	827	803	153	3.06
SBWC55	340	827	804	187	-	TBWC45	340	827	803	153	3.06
TBWC55	340	827	804	187	-	RBY1WC45	340	820	944	153	1.02
RBY1WC55	340	781	899	187	-	RBY50WC45	340	820	944	153	1.02
RBY30WC55	340	824	1056	187	-	RBY30WC45	340	824	892	153	3.06
RBY28WC55	340	781	956	187	-	RBY20WC45	340	827	884	153	1.02
RBY31WC55	340	781	849	187	-	RBY45aWC45	340	827	844	153	2.38
RBY32WC55	340	780	850	187	-	RBY52WC45	340	827	884	153	3.06
RBY46WC55	340	781	765	187	-	RBY55WC45	340	827	844	153	3.06
RBY60WC55	340	781	803	187	-	RBY35aWC45	340	827	844	153	3.06
RBY29WC55	340	782	869	187	-	RBY28WC45	340	820	1004	153	3.06
RBY33WC55	340	782	850	187	-	RBY31WC45	340	820	883	153	3.06
RBY38aWC55	340	781	849	187	-	RBY32WC45	340	820	883	153	3.06
RBY43WC55	340	781	849	187	-	RBY46WC45	340	821	806	153	3.06
RBY41WC55	340	782	808	187	-	RBY60WC45	340	820	843	153	3.06
RBY34WC55	340	782	808	187	-	RBY29WC45	340	821	912	153	3.06
RBY37aWC55	340	782	788	187	-	RBY33WC45	340	821	892	153	3.06
RBY40WC55	340	782	819	187	-	RBY38aWC45	340	820	891	153	3.06
RBY36WC55	340	782	800	187	-	RBY43WC45	340	820	891	153	3.06
RBY38cWC55	340	782	788	187	-	RBY41WC45	340	821	848	153	3.06
RBY16WC55	340	782	823	187	-	RBY34WC45	340	821	848	153	3.06
RBY1.5WC55	340	782	804	187	-	RBY37aWC45	340	821	828	153	3.06
RBY35bWC55	340	782	788	187	-	RBY38bWC45	340	821	864	153	3.06
RBY35cWC55	340	782	792	187	-	RBY40WC45	340	821	860	153	3.06
RBY45aWC55	340	782	804	187	-	RBY36WC45	340	821	840	153	3.06
RBY15WC55	340	782	823	187	-	RBY38cWC45	340	821	828	153	3.06
RBY44WC55	340	782	773	187	-	RBY1.5WC45	340	821	844	153	3.06
RBY35dWC55	340	782	800	187	-	RBY35bWC45	340	821	828	153	3.06
						RBY35cWC45	340	821	832	153	3.06
						RBY45aWC45	340	821	844	153	3.06
						RBY15WC45	340	821	864	153	3.06
						RBY44WC45	340	821	811	153	3.06
						RBY35dWC45	340	821	840	153	3.06
						RBY37bWC45	340	821	828	153	3.06

C=Cement, CA=Coarse Aggregate, FA=Fine Aggregate, W=Water, AD=Admixture

Workability of Concrete

The workability of concrete as slump (in cm) is shown in Figure 2 for W/C=0.55 and 0.45. For W/C=0.55, it is found that the workability of the recycled aggregate concrete is lower compared to the first class aggregate concrete (FBWC55) in most of the cases. It is due to the more internal friction among recycled aggregates. However, for W/C=0.45, most of the recycled aggregate cases show higher workability compared to the first class brick aggregate case (FBWC45).



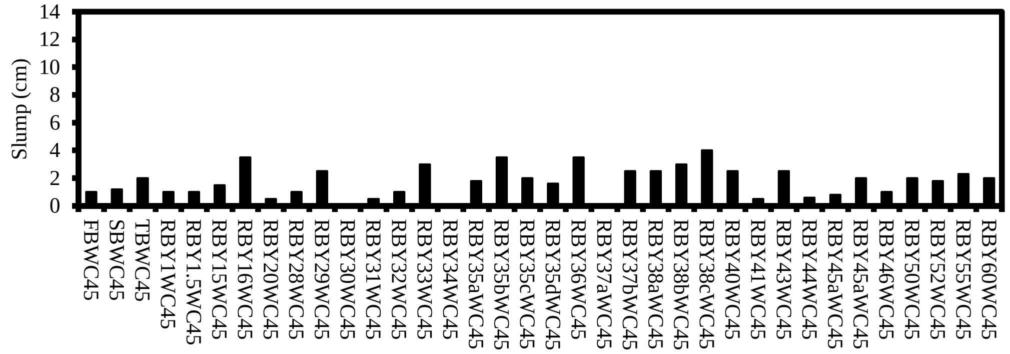


Figure 2. Workability of concrete (a) W/C=0.55-top, (b) W/C=0.45-bottom

Table 3. Properties of Aggregates Investigated

Type	Age (Years)	Sp. Gr.	Absorption Capacity (%)	Abrasion (%)	Type	Age (Years)	Sp. Gr.	Absorption Capacity (%)	Abrasion (%)
PB	-	2.10	9.50	26.13	RB	35d	2.09	12.87	42.40
FB	-	2.20	21.06	47.80	RB	36	2.09	14.24	49.80
SB	-	2.00	26.58	69.20	RB	37a	2.06	19.10	48.20
TB	-	2.00	29.11	76.88	RB	37b	2.06	18.50	48.32
RB	1	2.35	10.00	46.90	RB	38a	2.20	18.50	47.68
RB	1.5	2.10	17.17	46.03	RB	38b	2.15	15.90	47.36
RB	15	2.15	9.03	40.96	RB	38c	2.06	10.04	42.29
RB	16	2.03	10.91	37.17	RB	40	2.14	15.0	47.00
RB	20	2.20	17.92	49.55	RB	41	2.11	18.60	48.6
RB	28	2.50	15.85	40.33	RB	43	2.22	15.15	50.94
RB	29	2.27	18.30	53.18	RB	44	2.02	14.92	45.60
RB	30	2.32	9.12	47.26	RB	45a	2.10	22.70	50.58
RB	31	2.22	16.70	48.06	RB	45b	2.00	17.76	48.32
RB	32	2.22	18.40	43.82	RB	46	2.00	19.80	52.32
RB	33	2.22	15.80	47.16	RB	50	2.34	10.70	57.00
RB	34	2.11	15.47	45.88	RB	52	2.20	18.80	46.16
RB	35a	2.00	19.76	49.04	RB	55	2.10	23.15	43.44
RB	35b	2.06	17.86	48.45	RB	60	2.10	13.40	44.80
RB	35c	2.07	15.30	45.43					

Compressive Strength of Concrete

The compressive strength of concrete at 7, 14 and 28 days is shown in Figure 3. For W/C= 0.55, a reduction in strength of concrete is found for recycled brick aggregate concrete compared to the first class brick aggregate concrete (FBWC55) and picked brick aggregate concrete (PBWC55). But for W/C=0.45, in most of the cases, the compressive strength of recycled aggregate concrete is higher than the first class brick aggregate concrete (FBWC45). The results indicate that for a low W/C, recycled brick aggregates show better performance compared to high W/C with respect to compressive strength of concrete. Further investigation is necessary to clarify this observation. It is understood that for possible recycling of demolished concrete as coarse aggregate, it is necessary to reduce W/C.

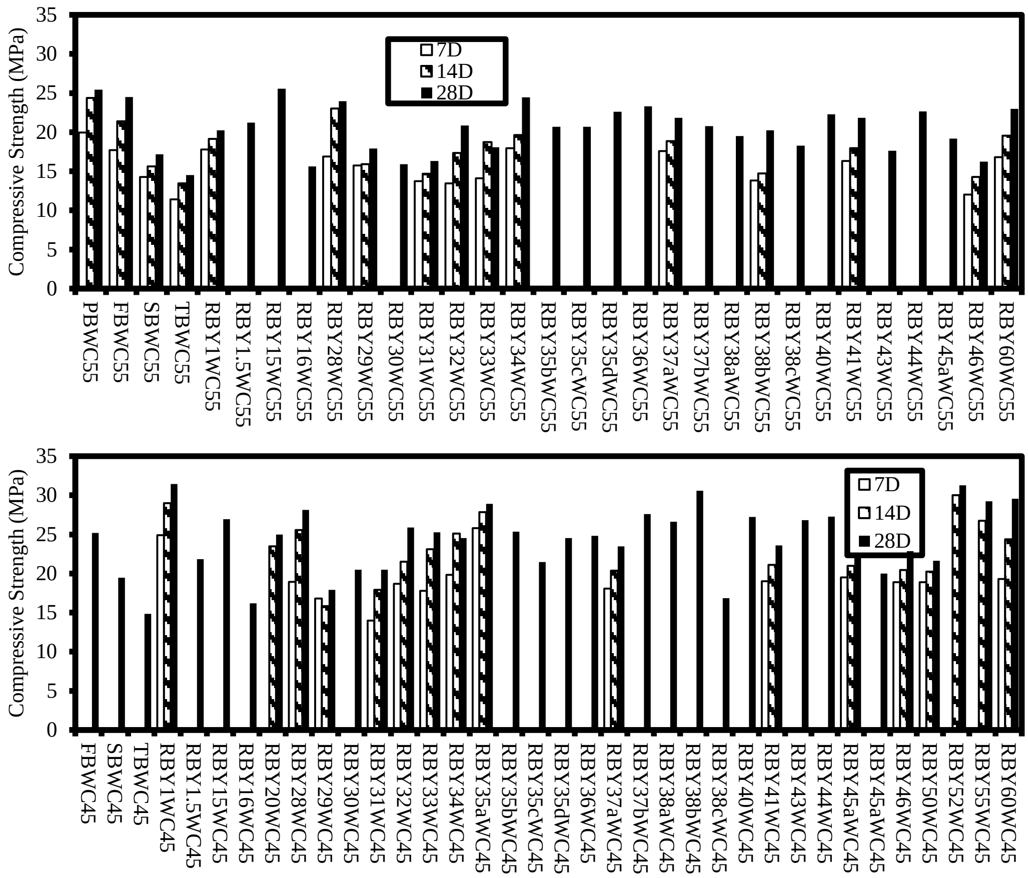


Figure 3. Compressive strength of concrete, (a) W/C=0.55-top, (b) W/C=0.45-bottom

Stress-Strain Curves of Concrete

The relationship between stress and strain of concrete specimen under uniaxial loading have been proposed by Desayi and Krishnan, 1964; Domingo and Chu, 1985 for stone aggregate concrete based on the experimental data. This relationship depends on water to cement ratio, cement content, coarse aggregate characteristics and many other properties of concrete. An attempt has been made to formulate a relationship between stress and strain of concrete made with recycled brick aggregate based on large number of experimental data of this study. Variation of normalized stress (ratio of stress to compressive strength) with strain for concrete specimens is shown in Figure 4. Based on these data, the following stress-strain relationship is proposed for recycled brick aggregate concrete:

$$\frac{f_c}{f_c'} = \frac{1.643\varepsilon}{0.001633+\varepsilon}, \quad R^2=0.92 \qquad 0 \le \varepsilon \le 0.0025 \qquad (1)$$

Where, f_c is stress at strain ε, and f'_c is compressive strength of concrete. This equation is valid till strain level of 0.0025. It is due to the limitation of recording strain data after maximum stress level.

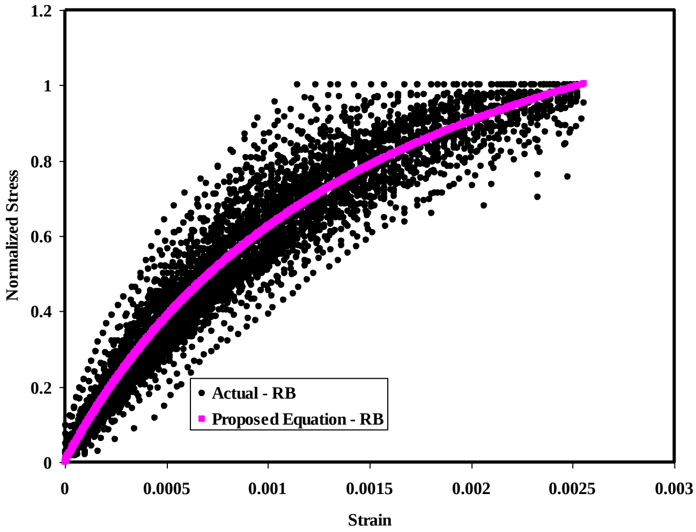


Figure 5. Stress-strain curves of concrete

Young's Modulus of Concrete

Young's modulus of concrete at 7, 14, and 28 days for different cases is shown in Figure 6. For W/C=0.55, the Young's modulus of concrete for recycled aggregate is lower compared to the same with picked brick aggregate concrete (PBWC55) (about 20~30% lower). However, for both W/C (0.55 and 0.45) compared to first class brick aggregate concrete (FBWC55), no reduction of Young's modulus of recycled brick aggregate concrete is found. Even, some recycled brick aggregate cases show higher Young's modulus of concrete compared to the first class brick aggregate concrete. Reduction of W/C of recycled aggregate concrete improves the Young's modulus**.** The variation of Young's modulus of recycled aggregate concrete with square root of compressive strength of concrete is shown in Figure 7. The following linear relationship is found between the Young's modulus and square root of compressive strength of concrete:

$$E_C = 3595\psi(t)\sqrt{f_C'} \qquad (2)$$

Where, E_c is Young's modulus of concrete in MPa, and f'_c is compressive strength of concrete in MPa and $\psi(t)$ is a time dependent constant.

$\psi(t) = 1$, 0.98, and 0.94 at 28, 14, and 7 days, respectively.

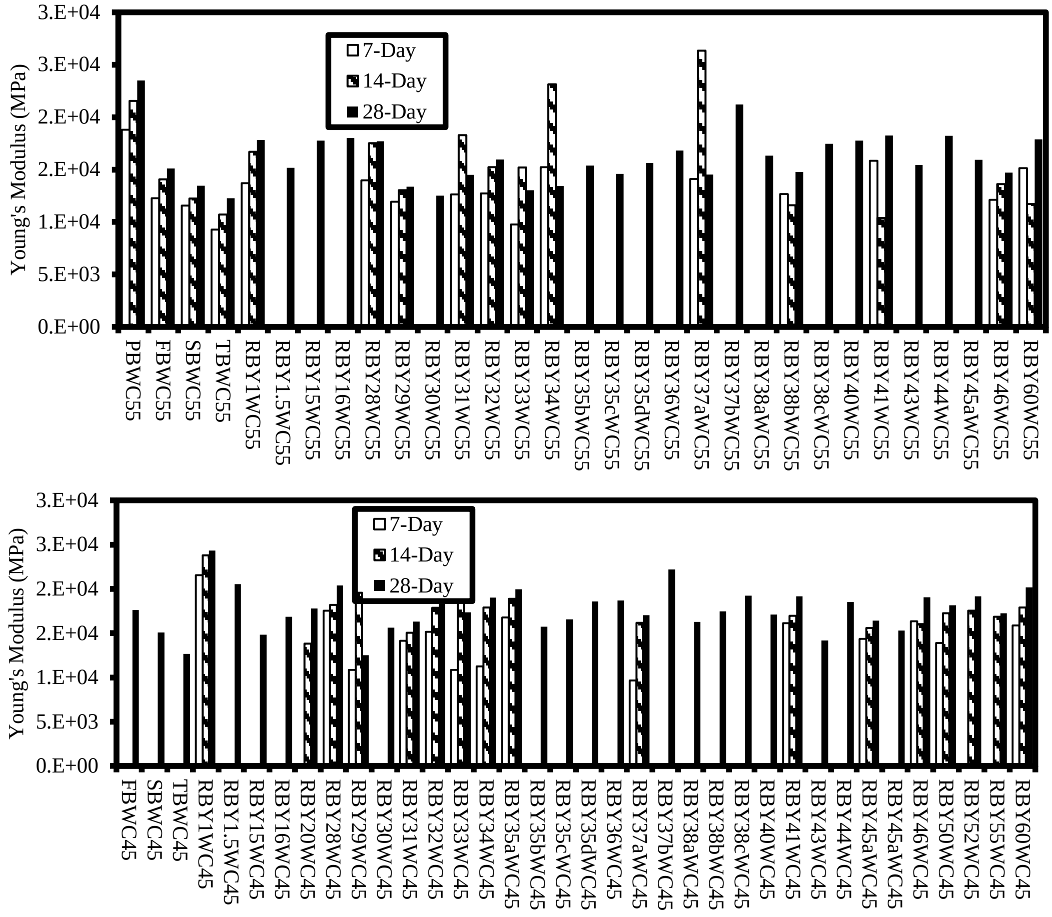


Figure 6. Young's modulus of concrete, (a) W/C=0.55-top, (b) W/C=0.45-bottom

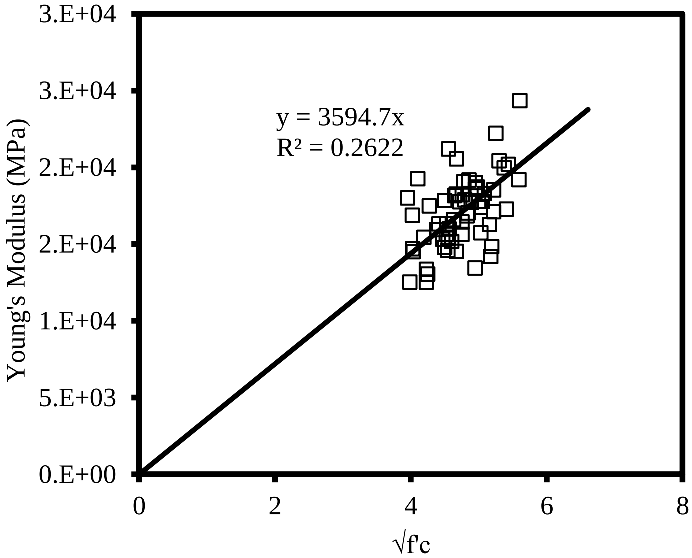


Figure 7. Relationship between Young's modulus and compressive strength at 28 days

Compressive Strength and Tensile Strength Relationship

The variation of tensile strength of recycled brick aggregate concrete with compressive strength is shown in Figure 8 for recycled brick aggregate. Based on the experimental data of recycled brick aggregate, the following relationship is proposed between tensile strength and compressive strength of concrete:

$$f_t = 0.50\sqrt{f_C^{'}} \quad (3)$$

Where, f_t is tensile strength of concrete in MPa and f'_c is compressive strength of concrete in MPa.

Compressive Strength and Wear Relationship

The variation of compressive strength of recycled brick aggregate concrete with the wear value of recycled brick aggregate is shown in Figure 9. It is observed that with an increase of wear value, the compressive strength of recycled aggregate concrete is reduced. The following relationships are proposed between compressive strength and wear value of recycled brick aggregate.

$$f_c^{'} = -0.57X + 47.7 \quad (4)$$

$$f_c^{'} = -0.49X + 48.6 \quad (5)$$

Where, f'_c is compressive strength of concrete at 28 days in MPa , and X is wear value of recycled brick aggregate in percentage.

Using these relationships , the strength of recycled brick aggregate concrete for a particular recycled brick aggregate with known wear value can be judged (for W/C= 0.55 and 0.45).

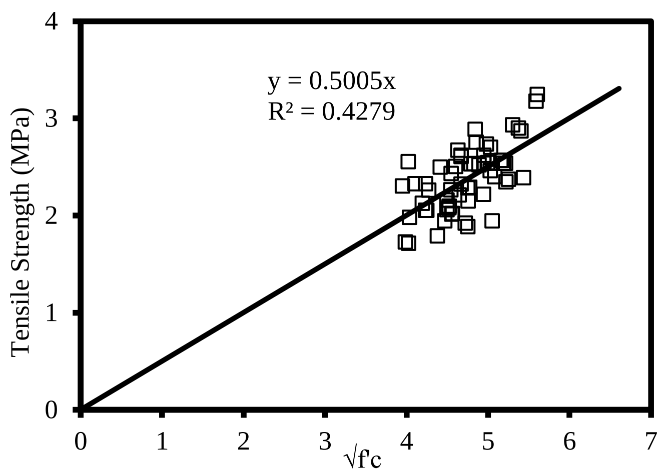


Figure 8. Relationship between tensile strength and compressive strength at 28 days

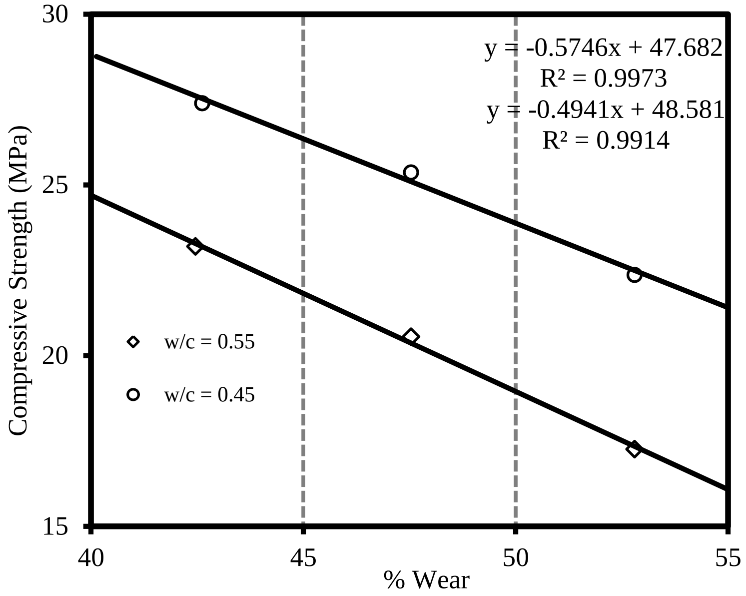


Figure 9. Wear of recycled aggregate versus compressive strength of concrete

Strength versus Time Relationship

The strength of recycled brick aggregate concrete at 7 and 14 days was normalized by the corresponding 28-day strength. Variation of normalized strength of recycled brick aggregate concrete with time is shown in Figure 10. The following time dependent relationships are proposed for compressive strength and tensile strength of recycled brick aggregate concrete. From these relationships, 28 days strength of concrete can be obtained from 3 days or 7 days or 14 days strength.

$$\frac{f_c}{f_c^{'}} = \frac{1.108t}{3.069+t}, \qquad R^2=0.80 \text{ (Compressive Strength)} \qquad (6)$$

$$\frac{f_t}{f_c^{'}} = \frac{0.1192t}{3.042+t}, \qquad R^2=0.20 \text{ (Tensile Strength)} \qquad (7)$$

Where, f_c and f_t are compressive strength and tensile strength at time t respectively. f'_c is 28-day compressive strength of concrete.

Statistical Analysis of Compressive Strength of Recycled Aggregate Concrete

Using normal distribution, the probability distribution function (PDF) and cumulative probability distribution function (CDF) of 28-day compressive strength of concrete collected from 33 different sites were determined and shown in Figure 11 and Figure 12 for W/C=0.55 and W/C=0.45 respectively. The average strength for W/C=0.55 is found to be 20.4 MPa and the same for W/C=0.45 is 24.7 MPa. The standard deviation was 2.7 MPa for W/C=0.55 and 4.0 MPa for W/C=0.45.

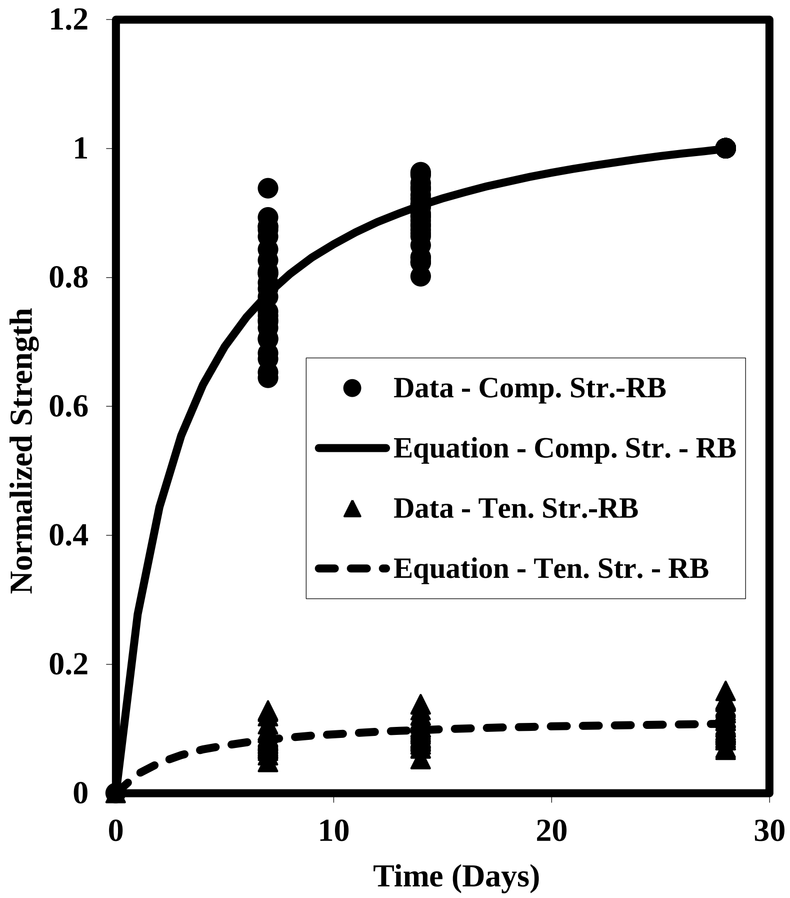


Figure 10. Variation of normalized strength of concrete with time

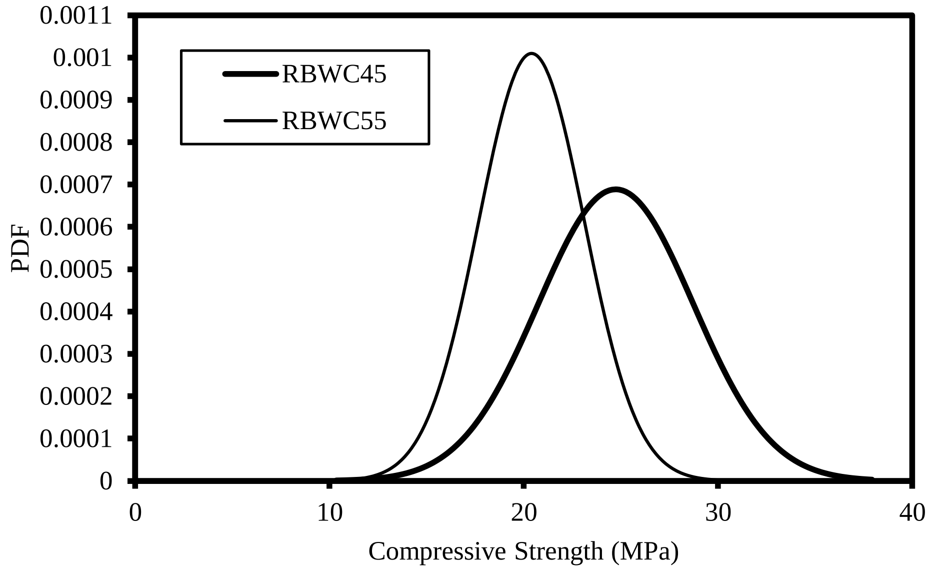


Figure 11. PDF for compressive strength of concrete - W/C=0.55 and 0.45

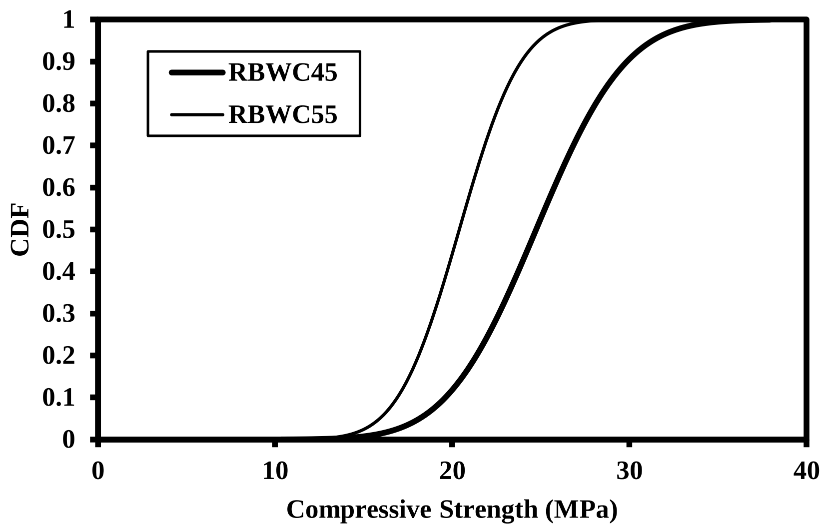


Figure 12. CDF for compressive strength of concrete - W/C=0.55 and 0.45

CONCLUSIONS

From the scope of this investigation on recycling of brick aggregate concrete, the following conclusions are drawn:

- In most of the cases, compared to the first class brick aggregate, the recycled aggregates show better performance with respect to abrasion and absorption capacity,
- For W/C=0.55, the workability of recycled aggregate concrete is relatively lower compared to the workability of the first class brick aggregate concrete,
- For W/C=0.55, the recycled aggregate concrete gives lower strength compared to first class brick aggregate concrete. If W/C is reduced (from 0.55 to 0.45), the strength and Young's modulus of concrete are improved significantly,
- The average strength of recycled aggregate concrete is found to be 24.7 MPa and 20.4 MPa for W/C=0.45 and 0.55 respectively,
- The relationship between the Young's modulus and compressive strength of recycled aggregate concrete is proposed,
- Strength (both for compressive and tensile strength) versus time relationship for recycled brick aggregate concrete is proposed,
- The relationships between wear value of recycled brick aggregate and compressive strength of recycled brick aggregate concrete for W/C=0.45 and 0.55 are proposed that can be used as a guideline to estimate the compressive strength of recycled brick aggregate concrete with the variation of wear value. If the wear value of recycled brick aggregate is known or determined from a concrete laboratory, then the compressive strength of concrete from the wear value of recycled brick aggregate can be judged for W/C=0.55 and W/C=0.45.

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