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Recycling of Concrete Made with Brick Aggregate

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ABSTRACT

This paper investigates the possibility of recycling of demolished concrete blocks made with brick aggregates as coarse aggregate. For this, demolished concrete blocks from seventeen different demolished building sites were collected and crushed into coarse aggregates. As virgin aggregate, first class brick aggregates (normal brick aggregate) were investigated. About 200 concrete cylinders were made using normal and recycled brick aggregates with W/C= 0.45 and 0.55. Test items include slump, unit weight, compressive strength, tensile strength, Young's modulus, and stress-strain curve.

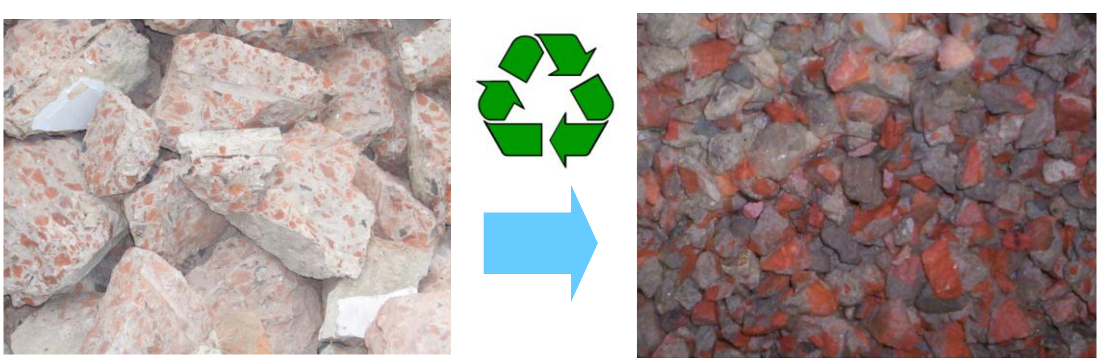
For the same W/C, recycled brick aggregate concrete shows lower compressive strength and Young's modulus compared to the normal brick aggregate concrete. The average strength of recycled brick aggregate concrete is found at 25.5 MPa (3700 psi) and 19.05 MPa (2762 psi) for W/C=0.45 and 0.55 respectively. The results indicate that recycled brick aggregates can be utilized for new construction works as normal brick aggregates.

INTRODUCTION

Concrete consumption in the world is estimated at two tons per capita per year (equivalent to 12 billion tons) [Mehta 2002]. To make this huge volume of concrete, 1.5 billion tons of cement, 9.3 billion tons of aggregate, 1.2 billion tons of water are necessary. Also, about 1.5 billion tons of steel is 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, 30% 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 (after breaking into 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 in Bangladesh. Studies related to the recycling of demolished concrete are generally found for stone chips made concrete [Alan 1977 and Gomez-Soberon et al 2002]. Therefore, investigations on recycling of brick made demolished concrete are necessary. With this background, this study was planned.

For investigation, demolished concrete blocks were collected from demolished building sites and broken into pieces as aggregate as shown in Figure 1. Before making concrete, the aggregates were investigated for absorption capacity, unit weight, and abrasion. Standard grading of the aggregates were controlled.\



Demolished Concrete Blocks

(Collected from demolished building sites)

Recycled Coarse Aggregate

(After crushing concrete blocks)

Fig.1. Demolished Concrete Block and Recycled Aggregates

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 workability of concrete was also measured by slump test. The results were compared with normal aggregate concrete.

EXPERIMENTAL METHODS

Demolished concrete blocks were collected from the structural members of the sixteen demolished buildings of age 20, 28, 29, 30, 31, 32, 33, 35, 38, 43, 45, 46, 50, 52, 55, and 60 years. The structural members of these buildings were made with brick aggregates. One-year old cylinder concrete specimens were also broken into pieces as recycled coarse aggregate for investigation. The collected demolished concrete blocks were broken into pieces manually. Demolished concrete blocks and recycled brick aggregates (denoted as RB) 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 (normal brick aggregate denoted as NB) were used. The fineness modulus (FM), water absorption and specific gravity of sand used in this investigation were 2.64, 3.9%, and 2.61, respectively. Normal tap water was used as mixing water. The temperature of the mixing water was about 20^{o}C. Saturated surface dry sand and aggregate were used for making concrete.

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. Thirty different cases were investigated as summarized in Table 1 with the variation of age of the demolished concrete blocks and W/C. The mixture proportions of the investigated cases are summarized in Table 2. W/C ratios of concrete were 0.55 and 0.45. Cement content of concrete was 340 kg/m^3. Sand to total aggregate volume ratio was 0.44. Naphthalene based superplasticizer was used for W/C=0.45. After mixing, the workability of concrete was measured by a slump cone. Cylinder concrete specimens were made and demolded after one day of casting. Later the specimens were cured under wet jute bags continuously. The compressive strength of concrete was measured at 7, 14, and 28 days. The strain of concrete specimens was measured by a strain measurement setup with two dial gauges. The gauge length was 100 mm. 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 200 concrete cylinders were investigated for 30 different cases as summarized in Table 1.

RESULTS AND DISCUSSIONS

Properties of Aggregates Investigated

The properties of recycled aggregates investigated are summarized in Table 3. As noted earlier, for comparison, first class brick aggregates, i.e. normal brick aggregate (denoted as NB) were investigated. One-year old recycled brick aggregates were obtained by crushing the cylinder specimens of age 1 year. Demolished concrete blocks from sixteen different demolished building sites were collected. The ages of the buildings were 20, 28, 29, 30, 31, 32, 33, 35, 38, 43, 45, 46, 50, 52, 55, and 60 years. The structural members of the demolished buildings were constructed using brick chips as brick chips were commonly used as coarse aggregate in Bangladesh. In most of the cases, the absorption capacity of the recycled aggregates is lower than the normal brick aggregates. Also, in most of the cases, no significant difference is found between the abrasion values of normal brick aggregate and recycled brick aggregate. The results indicate that the quality of recycled brick aggregate (old brick aggregate with old adhered mortar) is very similar to the quality of the normal brick aggregate commonly used in Bangladesh.

Table 1. Cylinder Concrete Specimens Investigated with Recycled Brick (RB) and Normal Brick (NB) Aggregates

Identification of Cases Investigated	Description (Type of Aggregate, Age*, and W/C)
NB 55	1st Brick Aggregate (Normal brick aggregate) - W/C Ratio 0.55
NB 45	1st Brick Aggregate (Normal Brick Aggregate) - W/C Ratio 0.45
RBY1-55	Recycled Brick Aggregate, Age = 1 Year, W/C = 0.55
RBY1 -45	Recycled Brick Aggregate, Age = 1 Year, W/C = 0.45
RBY20 -45	Recycled Brick Aggregate, Age = 20 Years, W/C = 0.45
RBY28 -55	Recycled Brick Aggregate, Age = 28 Years, W/C = 0.55
RBY28 -45	Recycled Brick Aggregate, Age = 28 Years, W/C = 0.45
RBY29 -45	Recycled Brick Aggregate, Age = 29 Years, W/C = 0.45
RBY29 -55	Recycled Brick Aggregate, Age = 29 Years, W/C = 0.55
RBY30 -55	Recycled Brick Aggregate, Age = 30 Years, W/C = 0.55
RBY30 -45	Recycled Brick Aggregate, Age = 30 Years, W/C = 0.45
RBY31 -45	Recycled Brick Aggregate, Age = 31Years, W/C = 0.45
RBY31 -55	Recycled Brick Aggregate, Age = 31Years, W/C = 0.55
RBY32 -55	Recycled Brick Aggregate, Age = 32 Years, W/C = 0.55
RBY32 -45	Recycled Brick Aggregate, Age = 32 Years, W/C = 0.45
RBY33 -45	Recycled Brick Aggregate, Age = 33 Years, W/C = 0.45
RBY33 -55	Recycled Brick Aggregate, Age = 33 Years, W/C = 0.55
RBY35 -45	Recycled Brick Aggregate, Age = 35Years, W/C = 0.45
RBY38 -45	Recycled Brick Aggregate, Age = 38 Years, W/C = 0.45
RBY38 -55	Recycled Brick Aggregate, Age = 38 Years, W/C = 0.55
RBY43 -45	Recycled Brick Aggregate, Age = 43 Years, W/C = 0.45
RBY43 -55	Recycled Brick Aggregate, Age= 43Years, W/C = 0.55
RBY45 -45	Recycled Brick Aggregate, Age= 45 Years, W/C = 0.45
RBY46 -55	Recycled Brick Aggregate, Age= 46 Years, W/C = 0.55
RBY46 -45	Recycled Brick Aggregate, Age= 46 Years, W/C = 0.45
RBY50 -45	Recycled Brick Aggregate, Age= 50 Years, W/C = 0.45
RBY52 -45	Recycled Brick Aggregate, Age= 52 Years, W/C = 0.45
RBY55 -45	Recycled Brick Aggregate, Age= 55 Years, W/C = 0.45
RBY60 -55	Recycled Brick Aggregate, Age= 60 Years, W/C = 0.55
RBY60 -45	Recycled Brick Aggregate, Age= 60 Years, W/C = 0.45

*The age of the demolished concrete buildings from which the concrete blocks were collected and later broken into recycled aggregate as coarse aggregate.

Workability of Concrete

The workability of concrete as slump (in cm) is shown in Figure 2 for W/C=0.55. It is found that the workability of the recycled aggregate concrete is lower compared to the normal brick aggregate concrete. It is due to the more internal friction among recycled aggregates with the presence of old mortar.

Table 2. Mixture Proportions of Concrete (30 Cases)

Cases	W/C	s/a	Unit Content (kg/m^3)				
			Cement	Sand	Aggregate	Water	Admixture (L)
NB55	0.55	0.44	340	788	842	187	0.00
NB45	0.45	0.44	340	827	884	153	3.06
RBY1 -55	0.55	0.44	340	781	899	187	0.00
RBY1 -45	0.45	0.44	340	820	944	153	1.02
RBY20 -45	0.45	0.44	340	827	884	153	1.02
RBY28 -55	0.55	0.44	340	781	956	187	0.00
RBY28 -45	0.45	0.44	340	820	1004	153	3.06
RBY29 -45	0.45	0.44	340	821	912	153	3.06
RBY29 -55	0.55	0.44	340	782	869	187	0.00
RBY30 -55	0.55	0.44	340	824	1057	153	0.00
RBY30 -45	0.45	0.44	340	824	892	153	3.06
RBY31 -45	0.45	0.44	340	820	883	153	3.06
RBY31 -55	0.55	0.44	340	781	849.	187	0.00
RBY32 -55	0.55	0.44	340	780	850.	187	0.00
RBY32 -45	0.45	0.44	340	820	883.	153	3.06
RBY33 -45	0.45	0.44	340	821	892	153	3.06
RBY33 -55	0.55	0.44	340	782	850	187	0.00
RBY35 -45	0.45	0.44	340	827	844	153	3.06
RBY38 -45	0.45	0.44	340	820	891	153	3.06
RBY38 -55	0.55	0.44	340	781	849	187	0.00
RBY43 -45	0.45	0.44	340	820	891	153	3.06
RBY43 -55	0.45	0.44	340	781	849	187	0.00
RBY45 -45	0.45	0.44	340	827	844	153	2.38
RBY46 -55	0.55	0.44	340	781	764	187	0.00
RBY46 -45	0.45	0.44	340	820	806	153	3.06
RBY50 -45	0.45	0.44	340	820	944	153	1.02
RBY52 -45	0.45	0.44	340	827	883	153	3.06
RBY55 -45	0.45	0.44	340	827	843	153	3.06
RBY60 -55	0.55	0.44	340	781	803	187	0.00
RBY60 -45	0.45	0.44	340	820	843	153	3.06

Compressive Strength of Concrete

The compressive strength of concrete for various cases 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 normal brick aggregate concrete. But for W/C=0.45, the compressive strength of recycled aggregate concrete is higher than the normal brick aggregate concrete. The results indicate that by reducing W/C, compressive strength of recycled aggregate concrete can be improved to the level of normal aggregate concrete with a high W/C.

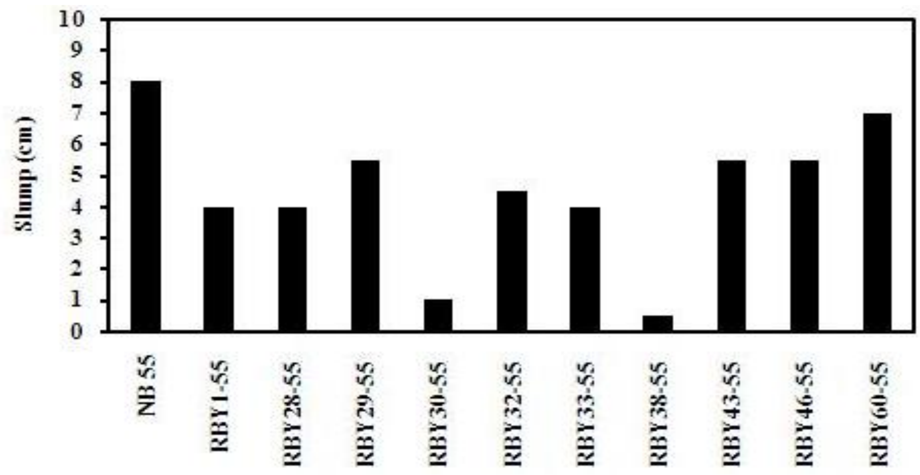


Fig.2. Workability of Concrete

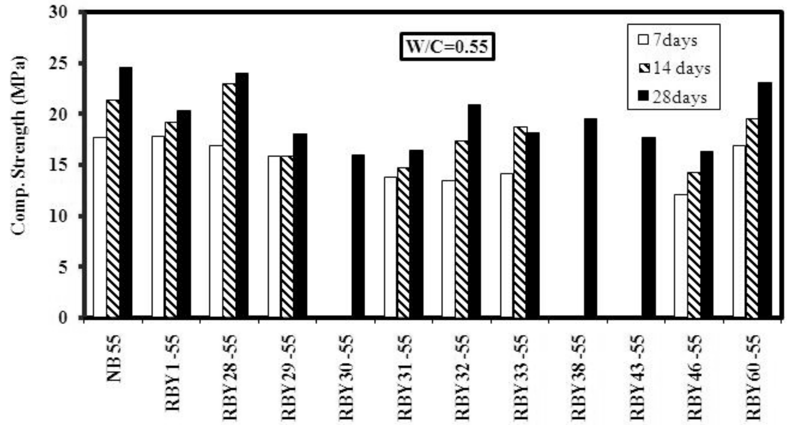
Table 3. Properties of Aggregates Investigated (Normal and Recycled Aggregates)

Age*	Type of Aggregate	FM**	Sp. Gr.	Absorption (%)	Abrasion(%)
-	Normal Brick (NB)	6.7	2.1	21.1	47.8
1 Year	Recycled Brick (RB)	6.7	2.35	10.0	46.9
20 Year	Recycled Brick (RB)	6.7	2.32	9.1	47.3
28 Year	Recycled Brick (RB)	6.7	2.34	10.7	57.0
29 Year	Recycled Brick (RB)	6.7	2.27	18.3	53.2
30 Year	Recycled Brick (RB)	6.7	2.32	9.1	47.3
31 Year	Recycled Brick (RB)	6.7	2.22	16.7	48.1
32 Year	Recycled Brick (RB)	6.7	2.22	18.4	43.9
33 Year	Recycled Brick (RB)	6.7	2.22	15.8	47.2
35 Year	Recycled Brick (RB)	6.7	2.00	19.8	49.0
38 Year	Recycled Brick (RB)	6.7	2.22	18.5	47.7
43 Year	Recycled Brick (RB)	6.7	2.22	15.2	51.0
45 Year	Recycled Brick (RB)	6.7	2.10	22.7	50.6
46 Year	Recycled Brick (RB)	6.7	2.00	19.8	52.3
50 Year	Recycled Brick (RB)	6.7	2.34	10.7	57.0
52 Year	Recycled Brick (RB)	6.7	2.20	18.8	46.2
55 Year	Recycled Brick (RB)	6.7	2.10	13.4	44.8
60 Year	Recycled Brick (RB)	6.7	2.10	13.4	44.8

*Age of the demolished concrete building from where concrete blocks were collected.

**Fineness Modulus

The compressive strength of concrete at 28 days with W/C=0.45 was normalized by the compressive strength of normal brick concrete at 28 days with W/C=0.55. The results are shown in Figure 4. For most of the cases, it is found that the strength of recycled aggregate concrete with W/C=0.45 is higher than the strength of normal brick aggregate concrete with W/C=0.55. Therefore, for possible recycling of demolished concrete as coarse aggregate, it is necessary to reduce W/C.



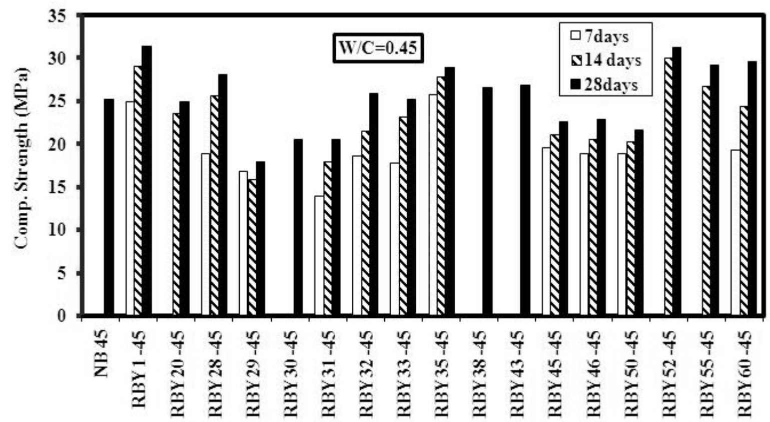


Fig.3. Compressive Strength of Concrete

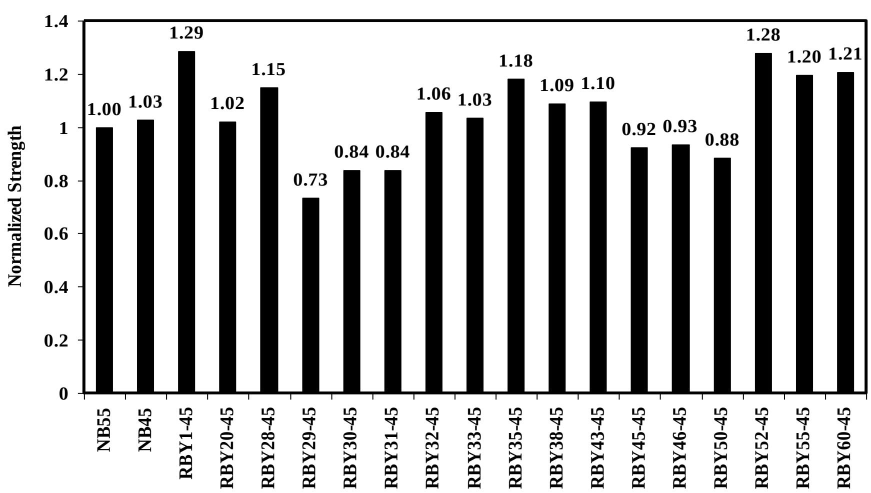


Fig.4. Normalized Compressive Strength of Concrete

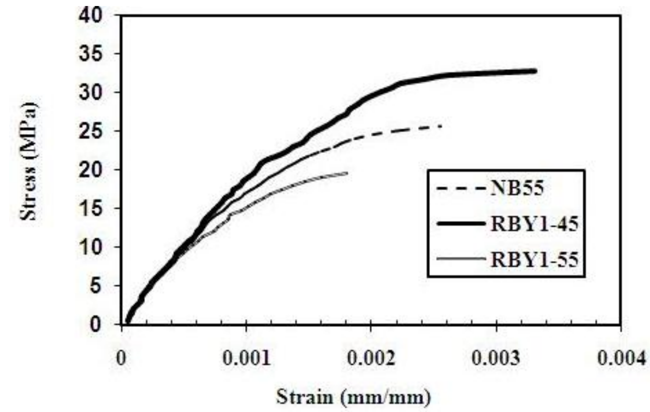


Fig.5. Stress-Strain Curves of Concrete

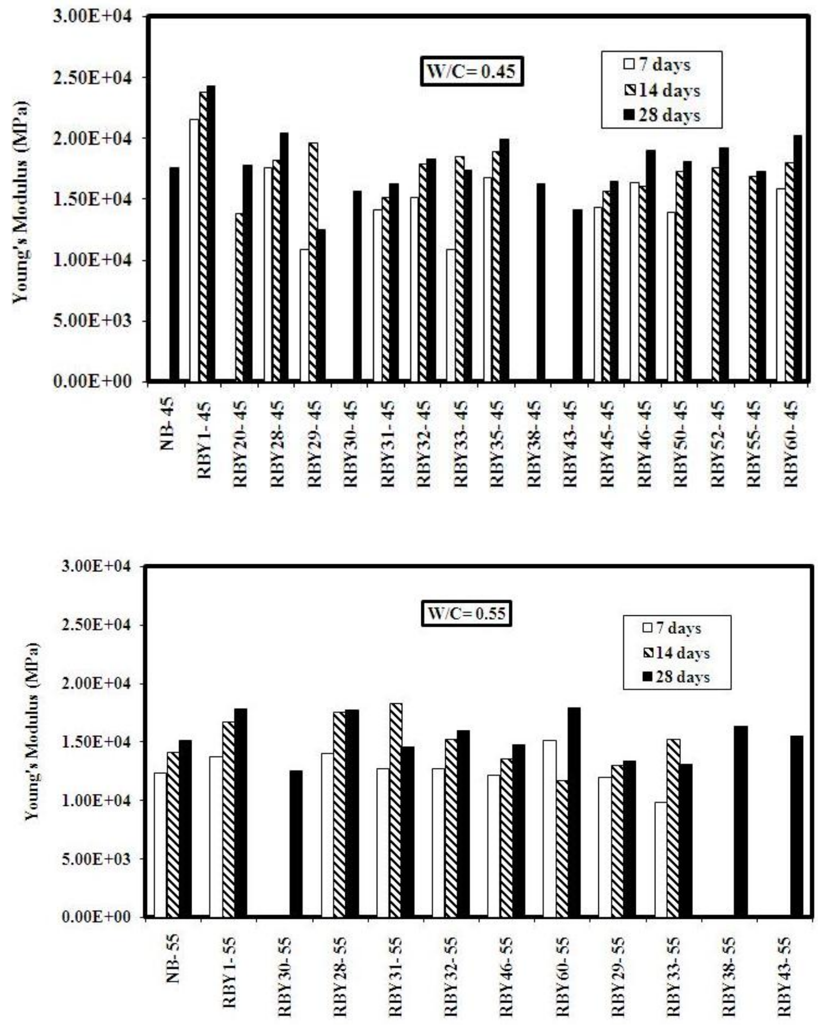


Fig.6. Young's Modulus of Concrete

Stress-Strain Curves of Concrete

Stress-strain curves of normal brick and 1-year recycled brick aggregate are shown in Figure 5. 1 year old recycled aggregates were made by breaking concrete cylinders made with normal brick aggregate. A flatter stress-strain curve is found for recycled aggregate concrete compared to the normal aggregate concrete for W/C=0.55. It is expected due to the adhered mortar with recycled aggregate as well as formation of internal micro cracks in the process of making coarse aggregate from demolished concrete blocks. However, for W/C=0.45 (RBY1-45) a steeper stress-strain curve is found compared to the normal aggregate concrete with W/C=0.55. It indicates that Young's modulus of recycled aggregate concrete s also increased wth the reduction of W/C.

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 same W/C, the Young's modulus of concrete for recycled aggregate is lower compared to the same with normal brick aggregate concrete (about 20~30% lower). The reason is explained in the previous section. Reduction of W/C of recycled aggregate concrete improves the Young's modulus. The recycled aggregates with a lower abrasion value give a higher Young's modulus (Table 3 and Figure 6). The variation of Young's modulus of recycled aggregate concrete with square root of compressive strength of concrete is shown in Figure 7. A linear relationship is found between the Young's modulus and square root of compressive strength of concrete.

Compressive Strength and Wear Relationship

The variation of compressive strength of recycled aggregate concrete with the wear value of recycled coarse aggregate is shown in Figure 8. It is observed that with an increase of wear value, the compressive strength of recycled aggregate concrete is reduced. Using these relationships (Figure 8), the expected strength of recycled aggregate concrete made with recycled aggregate with a known wear value can be judged (for similar mixture proportion).

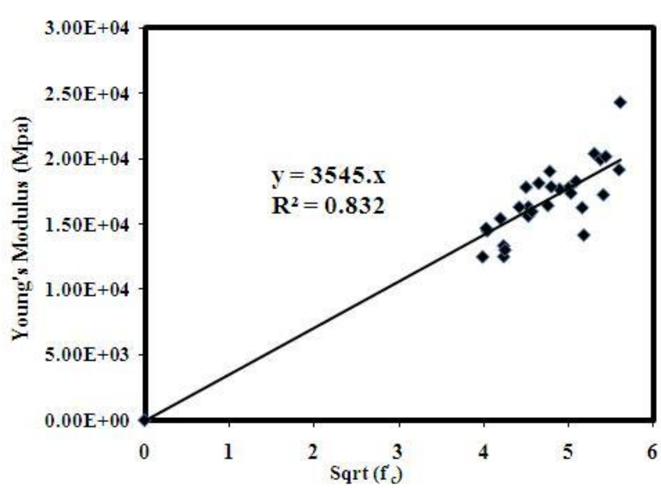


Fig.7. Relationship between Young's Modulus and Compressive Strength at 28 Days

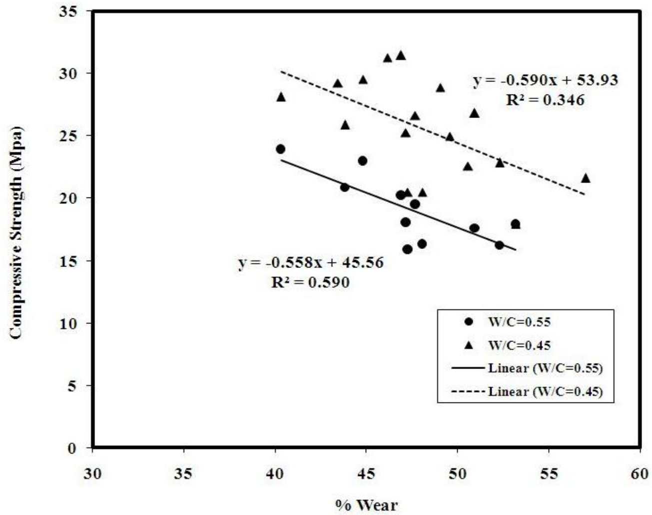


Fig.8. Wear of Recycled Aggregate versus Compressive Strength of Concrete

Statistical Analysis of Compressive Strength of Recycled Aggregate Concrete

The cumulative probability distribution function (CDF) of 28-day compressive strength of concrete collected from 17 different sites is shown in Figure 9 using normal distribution. The average strength (with cumulative probability = 0.5) for W/C=0.55 was 19.05 MPa (2762 psi) and the same for W/C=0.45 was 25.50 MPa (3700 psi). The standard deviation was 2.70 MPa (392 psi) for W/C=0.55 and 4 MPa (580 psi) for W/C=0.45. The ten percentile values (with cumulative probability = 0.1) of 28-day compressive strength of concrete were 15.5 MPa (2248 psi) and 20.5 MPa (2973 psi) for W/C=0.55 and W/C=0.45 respectively. It is important to note that similar strength is generally found for concrete made with normal brick aggregates. The results indicate that the recycled brick aggregate can be utilized for new construction works with design compressive strength requirement of 19 MPa to 25.5 MPa

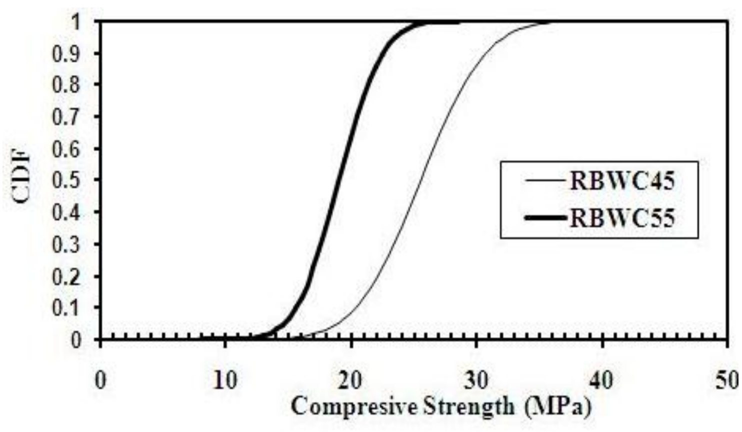


Fig. 9. Cumulative Probability Density Function (CDF) for Recycled Aggregate Concrete – W/C=0.55 and 0.45

CONCLUSIONS

From the scope of this investigation, the following conclusions are drawn:

- In most of the cases, compared to the normal brick aggregate, the recycled aggregates show better performance with respect to abrasion and absorption capacity,
- For W/C =0.55, the recycled aggregate concrete shows lower strength compared to normal brick aggregate concrete. However, if W/C is reduced to 0.45, the strength and Young's modulus of concrete are increased to the level or higher that the normal brick aggregate concrete made with W/C=0.55,
- The average strength of recycled aggregate concrete is found at 25.5 MPa (3700 psi) and 19.05 MPa (2762 psi) for W/C=0.45 and 0.55 respectively,
- The relationship between the Young's modulus and strength of recycled aggregate concrete is proposed,
- The relationship betweens wear value of recycled aggregate and compressive strength of recycled aggregate concrete for W/C=0.45 and 0.55 are proposed.

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