Recycling of Demolished Concrete

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 33 different sites were collected and crushed into coarse aggregates. As virgin aggregate, first class brick aggregates (normal brick aggregate) were investigated. About 350 concrete cylinders of diameter 150mm and height 300mm 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 W/C = 0.55, recycled brick aggregate concrete shows lower compressive strength compared to the normal brick aggregate concrete. The results are improved for W/C=0.45. The average strength of recycled brick aggregate concrete is found at 25.5 MPa (3700 psi) and 20.7 MPa (3000 psi) for W/C=0.45 and 0.55 respectively. The results indicate that recycled brick aggregates can be used for new construction works instead of normal brick aggregates.

Keywords: Recycling, Compressive Strength, Tensile Strength, Stress-Strain, Young's Modulus.

1. Introduction

Concrete consumption in the world is estimated at two tons per capita per year (equivalent to total consumption of 12 billion tons) [Mehta 2002]. To make this huge volume of concrete, 1.5 billion tons of cement, 9.3 billion tons of aggregate and 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 as coarse aggregate 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 currently 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 general acceptance of using recycled aggregate are developed, there will be no requirement for normal aggregate with the utilization of 100% of demolished concrete as coarse aggregate in new construction works.

In Bangladesh, the volume of demolished concrete is increasing due to deterioration of concrete structures as well as the replacement of many low-rise buildings by relatively high-rise buildings caused by booming of real estate business. Disposal of the demolished concrete is becoming a great concern to the developers of the buildings. If 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 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, Ravindrajah 1988, Chen 2003]. Therefore, investigations on recycling of demolished brick aggregates 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 Fig 1. Before making concrete, the aggregates were investigated for absorption capacity, unit weight, and abrasion. Standard grading of the aggregates were controlled as per ASTM.

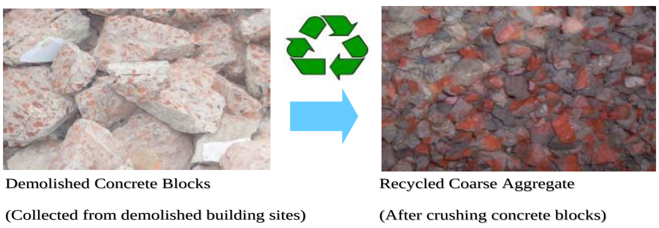

Figure 1: Demolished Concrete Block and Recycled Aggregates

Cylinder concrete specimens of diameter 150 mm and height 300 mm were made and tested for compressive strength, tensile strength, Young's modulus, and stress-strain curves. The workability of concrete was also measured by slump test. The results of recycled aggregate and recycled aggregate concrete were compared with the same results of normal aggregate.

2. Experimental Methods

Demolished concrete blocks were collected from the structural members of thirty two demolished buildings of age varied from 1 year to 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 Fig. 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±5^{o}C. Saturated surface dry(SSD) 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. Fifty eight (58) different cases were investigated as summarized in *Table 1* with the variation of age of the demolished concrete blocks and W/C. For mix design of concrete, sand to aggregate volume ratio was 0.44, cement content was 340 kg/m^3 and air content was 2%. Naphthalene based superplasticizer was used for W/C=0.45 at a dose of 9 ml per kg of cement. After mixing, the workability of concrete was measured by a slump cone. Cylindrical concrete specimens were made and demoulded 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 350 concrete cylinders were investigated for 58 different cases as summarized in *Table 1*.

3. Experimental Results and Discussion

3.1 Properties of Aggregate Investigated

The properties of recycled aggregates investigated are summarized in *Table 2*. 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 thirty two different demolished building sites were collected. The ages of the buildings were 1.5, 15, 16, 20, 28, 29, 30, 31, 32, 33, 34, 35(four sites, denoted as 35a, 35b, 35c and 35d), 36, 37(two sites, denoted as 37a and 37b), 38(three sites, denoted as 38a, 38b, and 38c), 40, 41, 43, 44, 45(two sites, denoted as 45a, and 45b), 46, 50, 52, 55, and 60. The structural members of the demolished buildings were constructed using brick chips as

Table 1: Identification of Cases Investigated (Type of Aggregate, Age, and W/C)*

Case No.	*Symbol*	***Explanation***
1 ~ 26 (W/C=0.55)	*NB 55, RB 1-55, RB 1.5 – 55, RB 15-55, RB 28-55, RB 29-55, RB 30-55, RB 31-55, RB 32-55, RB 33-55, RB 34-55, RB 35a-55, RB 35b-55, RB 35c-55, RB 36-55, RB 37a-55, RB 37b-55, RB 38a-55, RB 38b-55, RB 40-55, RB 41-55, RB 43-55, RB 44-55, RB 45-55, RB 46-55, RB 60-55.*	*NB – Normal Brick Aggregate, The digit after NB 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.*
27 ~ 58 (W/C=0.45)	*NB 45, RB 1-45, RB 1.5-45, RB 20-45, RB 28-45, RB 29-45, RB 30-45, RB 31-45, RB 32-45, RB 33-45, RB 34-45, RB 35a-45, RB 35b-45, RB 35c-45, RB 35c-45, RB 35d-45, RB 36-45, RB 37a-45, RB 37b-45, RB 38a-45, RB 38b-45, RB 40-45, RB 41-45, RB 43-45, RB 44-45, RB 45a-45, RB 45b-45, RB 46-45, RB 50-45, RB 52-45, RB 55-45, RB 60-45.*	

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

Table 2: Properties of Aggregate

Type	*Age (Years)*	*Sp. Gr.*	*Absorption Cap. (%)*	*Abrasion (%)*	*Type*	*Age (Years)*	*Sp. Gr.*	*Absorption Cap. (%)*	*Abrasion (%)*
NB	**-**	*2.20*	*21.10*	*47.80*	*RB*	*36*	*2.09*	*14.24*	*49.80*
RB	*1*	*2.35*	*10.00*	*46.90*	*RB*	*37a*	*2.06*	*19.10*	*48.20*
RB	*1.5*	*2.10*	*17.17*	*46.03*	*RB*	*37b*	*2.06*	*18.50*	*48.32*
RB	*15*	*2.15*	*9.03*	*40.96*	*RB*	*38a*	*2.20*	*18.50*	*47.68*
RB	*16*	*2.03*	*10.91*	*37.17*	*RB*	*38b*	*2.15*	*15.90*	*47.36*
RB	*20*	*2.20*	*17.92*	*49.55*	*RB*	*38c*	*2.06*	*10.04*	*42.29*
RB	*28*	*2.50*	*15.85*	*40.33*	*RB*	*40*	*2.14*	*15.0*	*47.00*
RB	*29*	*2.27*	*18.30*	*53.18*	*RB*	*41*	*2.11*	*18.60*	*48.6*
RB	*30*	*2.32*	*9.12*	*47.26*	*RB*	*43*	*2.22*	*15.15*	*50.94*
RB	*31*	*2.22*	*16.70*	*48.06*	*RB*	*44*	*2.02*	*14.92*	*45.60*
RB	*32*	*2.22*	*18.40*	*43.82*	*RB*	*45a*	*2.10*	*22.70*	*50.58*
RB	*33*	*2.22*	*15.80*	*47.16*	*RB*	*45b*	*2.00*	*17.76*	*48.32*
RB	*34*	*2.11*	*15.47*	*45.88*	*RB*	*46*	*2.00*	*19.80*	*52.32*
RB	*35a*	*2.00*	*19.76*	*49.04*	*RB*	*50*	*2.34*	*10.70*	*57.00*
RB	*35b*	*2.06*	*17.86*	*48.45*	*RB*	*52*	*2.20*	*18.80*	*46.16*
RB	*35c*	*2.07*	*15.30*	*45.43*	*RB*	*55*	*2.10*	*23.15*	*43.44*
RB	*35d*	*2.09*	*12.87*	*42.40*	*RB*	*60*	*2.10*	*13.40*	*44.80*

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 commonly used in Bangladesh. 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.

3.2 Workability of Concrete

Workability of concrete for different aggregate with the variation of W/C is shown in Fig. 2. 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. However, workability of recycled aggregate concrete can be improved by application of a cement paste coating over the recycled aggregate[Paul et. al 2007, Hamiduzzaman et. al 2008, Sarwar et. al 2010]. These results were not included in this report**.**

3.3 Compressive Strength and Tensile Strength of Concrete

The compressive strength of concrete with the variation of aggregate and W/C is shown in Fig. 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 the normal aggregate concrete. Further study is necessary to understand the reasons behind this[Mohammed et. al 2007,2010].

The compressive strength of recycled aggregate concrete with the variation of the age of the recycled aggregate is shown in Fig. 4. The results indicate that quality of the concrete is very important for recycling compared to the age of the demolished building. Therefore, for future recycling, the concrete structures are to be made with quality concrete.

The tensile strength of concrete with the variation of aggregate and W/C is shown in Fig. 5. For W/C=0.55, it is found that the tensile strength of recycled aggregate concrete is lower compared to the same with normal aggregate concrete. However, same as compressive strength, the tensile strength of concrete is increased to the level tensile strength of concrete made with normal aggregate for W/C=0.45. It indicates, there is a possibility of improving interfacial transition zone (ITZ) around recycled aggregate for a low W/C. However, further study is necessary for this matter.

The variation of tensile strength of recycled aggregate concrete with the compressive strength of recycled aggregate concrete is shown in Fig. 6. The relationship shown in Fig. 6 is proposed between the tensile strength(f_t') and compressive strength(f_c') of recycled aggregate concrete.

$$f_c' = 6\sqrt{f_t'} \qquad (1)$$

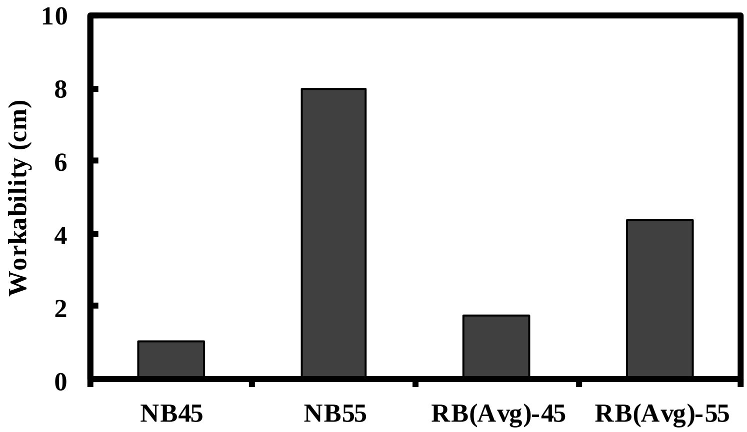

Figure 2: Workability of Concrete

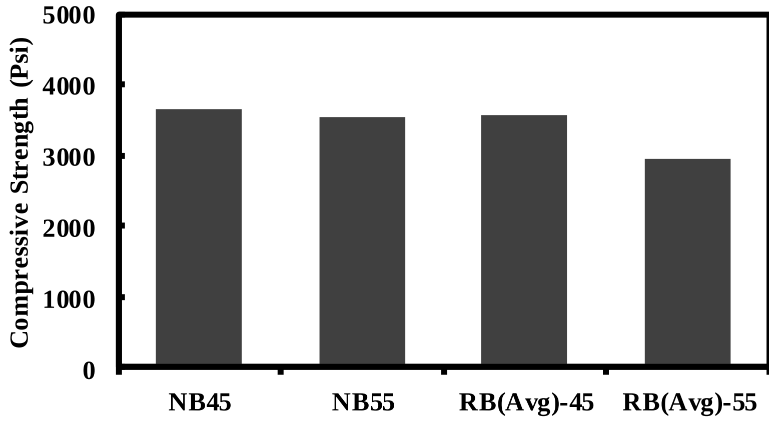

Figure 3: Compressive Strength of Concrete with the Variation of W/C

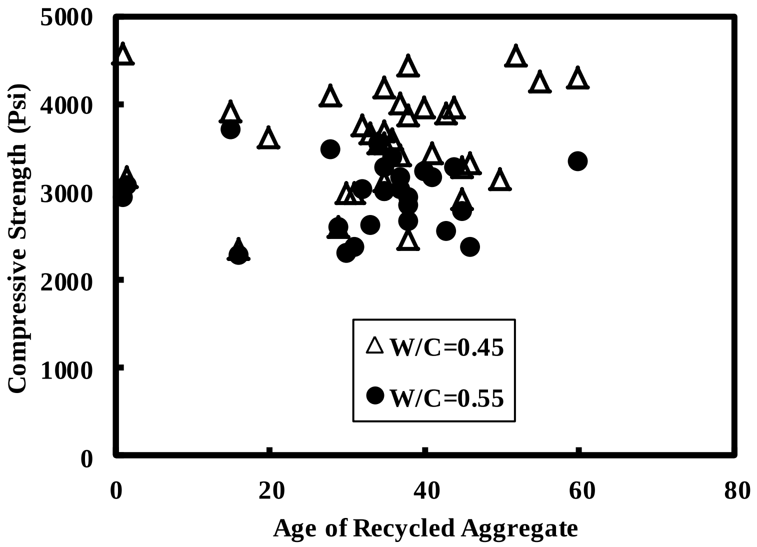

Figure 4: Compressive Strength of Concrete with the Variation of Age of Demolished Concrete

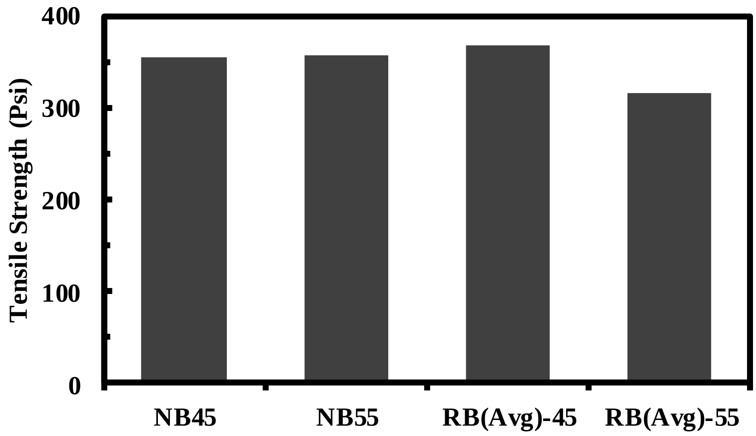

Figure 5: Tensile Strength of Concrete with the Variation of W/C

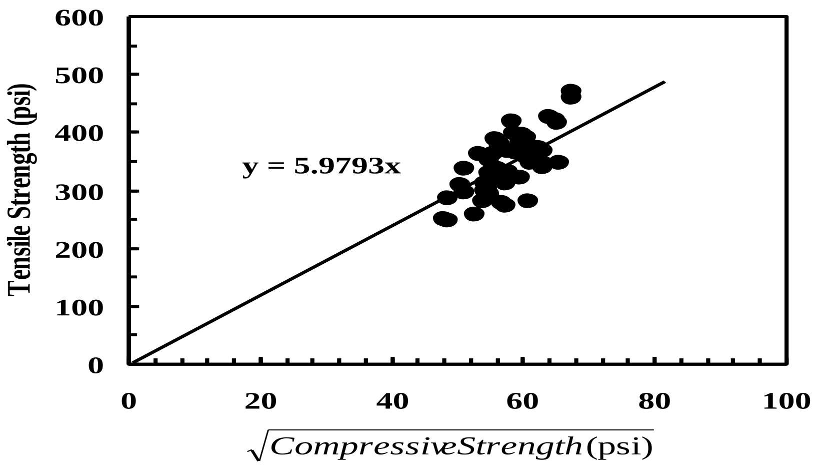

Figure 6: Tensile Strength versus Compressive Strength of Concrete

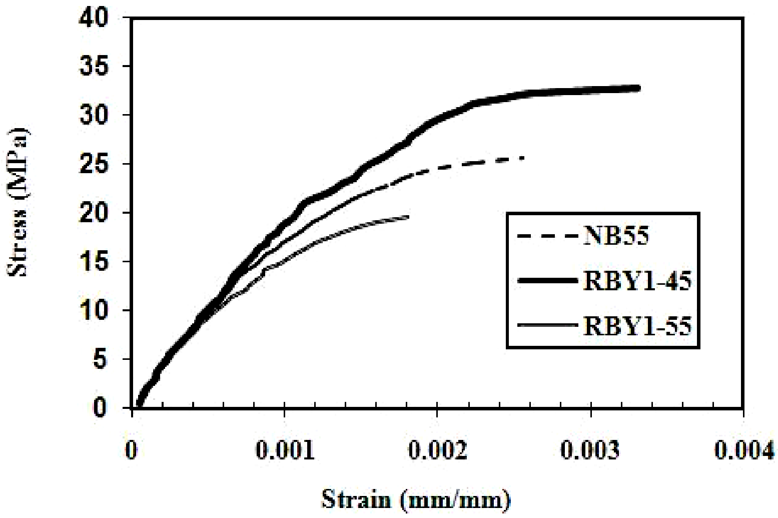

Figure 7: Stress-Strain Curves of Concrete

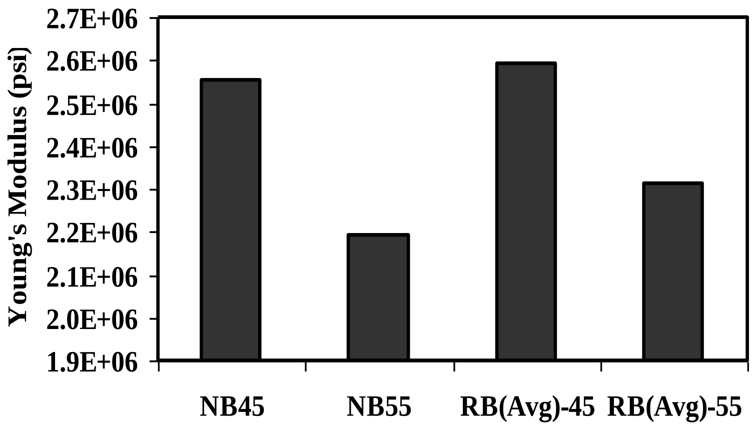

Figure 8: Young’s Modulus of Concrete with the Variation of W/C

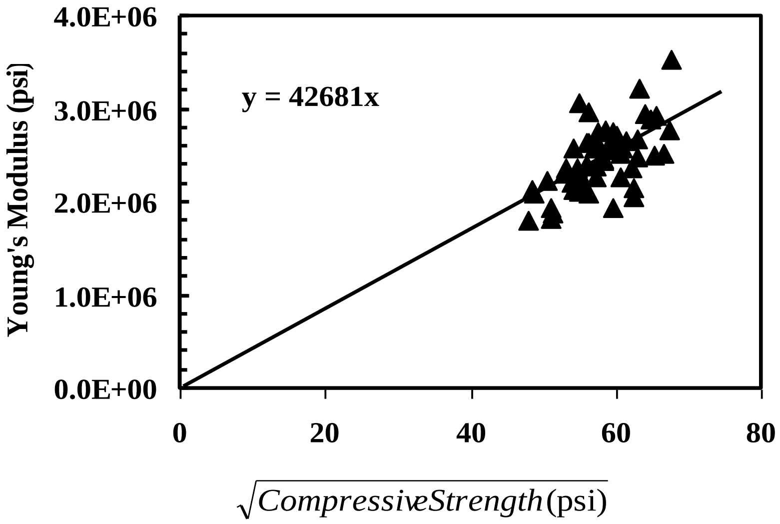

Figure 9: Young’s Modulus versus Compressive Strength of Concrete

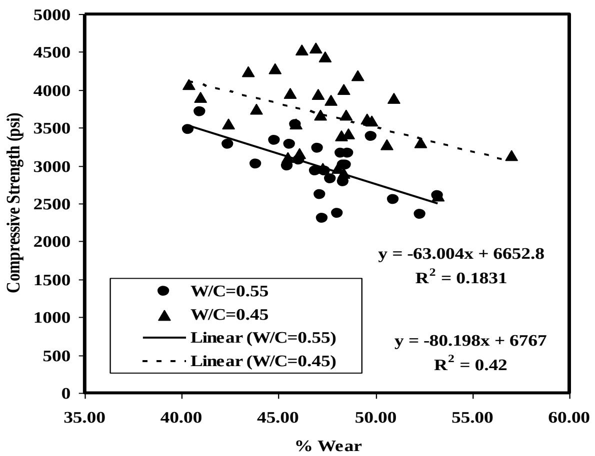

Figure 10: Compressive Strength of Concrete versus Wear

3.4 Stress-Strain Curves of Concrete

Stress-strain curves of normal brick and 1-year recycled brick aggregate are shown in Fig. 7. 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 with the reduction of W/C.

3.5 Young's Modulus of Concrete

Young's modulus of concrete with the variation of aggregate and W/C is shown in Fig. 8. For the same W/C, the Young's modulus of concrete for recycled aggregate is higher compared to the same with the normal brick aggregate concrete. It conflicts with the results of compressive strength of concrete explained earlier. More detailed investigations are necessary to understand the reasons related to this observation related to recycled brick aggregate concrete. The relationship shown in Fig. 9 is proposed between the Young's modulus($\boldsymbol{E_c}$) and compressive strength($\boldsymbol{f'_c}$) of recycled aggregate concrete.

$$\boldsymbol{E_c} = \mathbf{42681}\sqrt{\boldsymbol{f'_c}} \qquad (2)$$

3.6 Wear and Compressive Strength Relationship

The variation of compressive strength of recycled aggregate concrete with the wear value of recycled coarse aggregate is shown in Fig. 10. It is observed that with an increase of wear value, the compressive strength of recycled aggregate concrete is reduced. Using these relationships (as shown in Fig. 10), the expected strength of recycled aggregate concrete with a known wear value can be judged.

3.7 Statistical Analysis of Compressive Strength Data

The cumulative probability distribution function (CDF) and (PDF) of 28-day compressive strength of recycled aggregate concrete are shown in Fig. 11 and Fig. 12 using normal distribution. The average compressive strength (with cumulative probability = 0.5) for W/C=0.55 is found at 20.7 MPa (3000 psi) and the same for W/C=0.45 is found at 25.50 MPa (3700 psi). The standard deviation was 2.60 MPa (379 psi) for W/C=0.55 and 3.5 MPa (507 psi) for W/C=0.45. The ten percentile values (with cumulative probability = 0.1) of 28-day compressive strength of recycled aggregate concrete is found at 17.2 MPa (2500 psi) and 20.7 MPa (3000 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

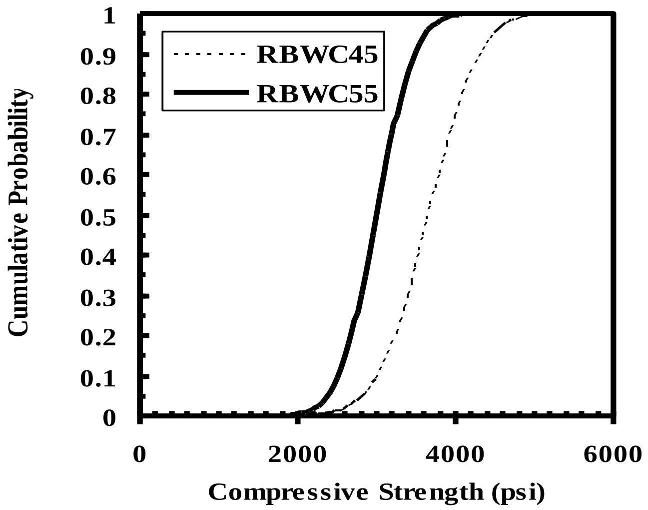

Figure 11: Cumulative Probability Distribution of Compressive Strength of Recycled Aggregate Concrete

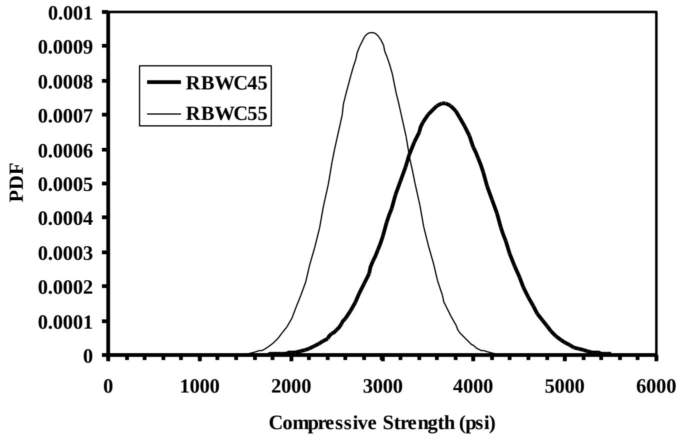

Figure 12: Probability Density Function of Compressive Strength of Recycled Aggregate Concrete

4. Conclusions

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

1. Compared to the normal brick aggregate, the recycled brick aggregates show better performance with respect to abrasion and absorption capacity,

2. 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 compressive strength of recycled aggregate concrete shows higher strength compared to normal brick aggregate concrete,

3. The average compressive strength of recycled aggregate concrete is found at 25.5 MPa (3700 psi) and 20.70 MPa (3000 psi) for W/C=0.45 and 0.55 respectively,

4. The relationship between the Young's modulus and compressive strength of recycled aggregate concrete is proposed,

5. The relationships between 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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