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A Comparative Case Study on Mix Design of Recycled Brick Chip Concrete and Concrete with Other Aggregate Materials for a Particular Strength

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The effects of aggregate type, size, and content on the behaviour of concrete is evident. It is well recognized that coarse aggregate plays an important role in concrete. Coarse aggregate typically occupies over one-third of the volume of concrete, and research indicates that changes in coarse aggregate can change the strength and fracture properties of concrete. To predict the behaviour of concrete under general loading requires an understanding of the effects of aggregate type, aggregate size, and aggregate content. This understanding can only be gained through extensive testing and observation. There is controversy, however, on the effects of coarse aggregate content on the compressive strength of concrete and the conditions to achieve the strength. Keeping this in mind, this paper deals with the actual amount of materials needed to achieve a particular strength, and the conditions, which greatly affect the gaining of this strength, putting special emphasis on different material conditions. It also puts an effort to find out the potentiality of recycled brick chips concrete along with other aggregates through compressive strength against time with different parameters.

Keywords: Aggregates, Concrete, Recycled Brick Chip, Stone, shingle, compressive strength.

1. Introduction

Concrete is a composite construction material composed primarily of aggregate, cement and water. Concrete is by far one of the most extensively used construction material in the world. It is well known for its ability to withstand huge amount of compressive force in comparison to the other building materials like timber and steel. The properties of aggregate materials may vary unexpectedly, so does the properties of concrete. The aim of mix design is to select an appropriate proportion of all concrete materials so that the desired strength can be achieved. Basing on the mix design proportions, by trial and error we must find the actual amount of the materials in the field so that workability, durability, economy and strength criteria are fulfilled. According to results of previous researches, the characteristics of recycled aggregate concretes vary considerably depending upon the quality and replacement level of recycled aggregate used. In this experiment, recycled aggregate produced by advanced recycling method was used. The replacement level of aggregate was set as the major variable, so that the mix proportions were established with variations in the percentage of coarse and fine aggregate replacement. The coarse aggregate used in the study showed about the similar properties as the natural

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aggregate. Therefore, 100% recycled coarse aggregate is used instead of fractioning it in mix proportions.

The objective of this research paper is mainly unidirectional. An endeavour was taken to find out the actual amount of materials needed to achieve a strength, and the conditions, which greatly affect the gaining of this strength, putting special emphasis on different material conditions against recycled concrete. For preparation of concrete we have used four types of materials as aggregate and they are recycled concretes, stone chips, shingles, and brick chips. Strength of concrete depends on different factors, mainly ingredient materials, field conditions, preparation procedures, climatic conditions etc. Concrete porosity i.e. voids in concrete that can be filled with air or with water, water/cement ratio, soundness of aggregate, aggregate-paste bond, and certain cement-related parameters i.e. parameters relating to the composition of the individual cement minerals and their proportions in the cement can affect the rate of strength growth and the final strengths achieved[7]. In the project experiment, due emphasis was given to these parameters so that the effect of quality control is rightly understood. The properties of cement, aggregate, sand etc. are also evaluated to ensure their effect on the strength of concrete.

Within the scope of this paper, Introduction is given in section 1, Literature Review is focused in Section 2, Methodology is described in section 3, testing and experimental procedure is discussed in section 4, Results are provided in Section 5 and Conclusion is drawn in Section 6.

2. Literature Review

2.1. Materials

Concrete is considered as a chemically combined artificial stone where there is an inert material acting as filler and a binding material which acts as a glue. Water is essential for mixing the ingredient and forming the bond among them. Also, water contributes in the process of gaining strength. The most widely used and important binding materials is cement. The inert materials used in concrete are termed as aggregates and for convenience are separated into fine and coarse aggregates. Sand, stone screenings are usually used as fine aggregate. Brick chips, broken stones, gravel clinkers, shingles, recycled concrete etc. are commonly used as coarse aggregate in Bangladesh. In concrete construction engineers use Portland Cement 90% of the time. Potable water is undoubtedly good for concreting. As discussed earlier, quality of these constituent materials directly affects the quality of concrete. Sometimes admixtures of different types are used in concrete to promote its performance but obviously they are of secondary importance.

2.1.1. Brick Chips

In Bangladesh and parts of West Bengal, India, where natural rock deposits are scarce, burnt clay bricks are used as an alternative source of coarse aggregate. In Bangladesh the use and performance of concrete made with broken brick as coarse aggregate are quite extensive and satisfactory. Clay can be burnt in its natural form as is done in brick-making and the product may be a source of coarse aggregate for concrete. Also, in brick-making, many bricks are rejected due to nonconformity with the required specifications. One such major nonconformity is the distorted form of brick produced due to the uneven temperature control in the kiln. These rejected bricks can also be a potential source of coarse aggregate. This would not only make good use of the otherwise waste material but would also help alleviate disposal problems. Despite extensive use of brick aggregate concrete in this region and the apparent satisfactory performance of the structures already built, no systematic investigation was conducted and properly documented. The current designs for brick aggregate concretes are based on intuition and accumulation of experience, rather than on sound experimental evidence. The practical experiences confidently showed us that the maximum range of compressive strength of concretes made with brick aggregate but without using any admixture is around 3000 psi. However, higher strength concrete (f_c' much greater than 3000 psi) can be used advantageously in compression members such as columns and piles. In columns, the reduction in size will lead to reduced dead load and subsequently to reduced total load on the foundation system. Smaller column size also means more available floor space to use. The relatively higher compressive strength per unit volume will also significantly reduce the dead load of flexural members. In addition, higher strength concrete possessing a highly dense microstructure is likely to enhance long-term durability of the structure. The mix proportion of the concrete is usually done either by the ACI method (1994) or the BS method (1985).In both methods, the coarse aggregate is the crushed natural stones and the unit weight of this concrete ranges from 140 to 152 pounds per cubic foot (pcf2) (Nilson and Darwin, 1997), whereas brick aggregate concrete weighing between 125-130 pcf can be termed as medium weight concrete in comparison with normal weight and light weight concrete (Akhteruzzaman and Hasnat 1983). Besides, the texture and surface roughness of brick aggregates are different from those of stone aggregate. So, the properties of brick aggregate concrete may not follow the same trends as those of stone aggregate concrete. Consequently, the present code specifications, which are based on stone aggregate concrete, may not be applicable for brick aggregate concrete.

2.1.2. Recycled Aggregate

The recycling of Construction and Demolition Wastes has long been accepted to have the possible to conserve natural resources and to decrease energy used in production. In some nations it is a standard substitute for both construction and maintenance, particularly where there is a scarcity of construction aggregate. The use of recycled aggregate weakens the quality of recycled aggregate concrete which limits its application. For improving the quality of recycled coarse aggregate, various surface treatment methods such as washing the recycled aggregates with water and diluted acid were investigated. Strength properties of the treated and untreated coarse aggregate were compared. The results indicated that the compressive, flexure and split tensile strength of recycle aggregate is found to be less than the natural aggregate. According to results of previous researches, the characteristics of recycled aggregate concretes vary considerably depending upon the quality and replacement level of recycled aggregate used. In this experiment, recycled aggregate produced by advanced recycling method was used. The replacement level of aggregate was set as the major variable, so that the mix proportions were established with variations in the percentage of coarse and fine aggregate replacement. The coarse aggregate used in the study showed about the similar properties as the natural aggregate. Therefore, 100% recycled coarse aggregate is used instead of fractioning it in mix proportions.

2.1.3. Stone Chips

It shall be crushed or broken from hard stone obtained from approved quarries of igneous or metamorphic origin. The stone chips shall be hard, strong, dense, durable, compact, close grained, homogeneous, fire resistant and angular in shape and shall be obtained from sources approved by Engineer. It shall be free from soft, friable, thin, flat, elongated or laminated and flaky pieces and free from dirt, clay lumps, and other deleterious materials like coal, lignite’s, silt, soft fragments, and other foreign materials which may affect adversely the strength & durability of concrete.

Stones shall have a crushing strength of not less than 200 kg/cm2. Stones with lesser crushing strength may be used in works with prior approval of the Engineer. Stone shall show water absorption of less than 5% of its dry weight when soaked in water for 24 hours.

2.1.4 Shingles

Construction sites, particularly Govt. Departments hesitates in the use of uncrushed coarse aggregate as so far, they are being supplied to them direct from river bed or by manual sieving without washing them with water. Thus, neither they are clean nor properly graded. In this booklet the readers will find that when quality uncrushed aggregates are available not only economically but locally, construction sites particularly Govt. Departments should not hesitate in the use of uncrushed aggregates from the river bed and save our environment, as crusher generate pollution. Further in all the Civil Engineering Codes uncrushed aggregates from river bed has been specified to be used in our all Civil Engineering Construction. In the production of crushed aggregate, the crushing plants generate dust. This ‘fugitive’ dust, if releases in the atmosphere untreated may pose pollution problem. Whereas, this pollution problem is not with the production of uncrushed (gravel/shingle) aggregate which is produces in the modern fully mechanized screening & washing plant. Angular shape of crushed aggregate required more water for a given workability. Thus, more cement will be required for a given water-cement ratio. More water-cement paste means less durability of concrete. Naturally formed surfaces of uncrushed aggregates (shingles) from river bed improved the workability and this is advantageous in terms of reduced water demand which produces more dense, impermeable and durable concrete.

2.2. Mix Proportions

Proportioning of the ingredients plays the most important role in obtaining a strong, durable, dense and economic concrete to suite all requirements depending on job conditions. Mix proportions depend on job requirements, material availability and material quality and design specifications. In brief, the effort in mix proportioning is to use a minimum amount of paste (and therefore cement) that will lubricate the mass while fresh and after hardening will bind the aggregate particles together strongly and fill the space between them. Any excess of paste involves greater cost, greater drying shrinkage, and greater susceptibility to percolation of water and therefore attack by aggressive waters and weathering actions. This is achieved by minimizing the voids by good gradation of aggregates .With the given materials the four variable factors to be considered, in connection with specifying concrete mixes are:

(a) Water/cement ratio.
(b) Cement/aggregate ratio.
(c) Gradation of aggregates.
(d) Consistency.

In the paper "Effect of Replacing Natural Coarse Aggregate by Brick Aggregate on the Properties of Concrete" by Mohammad Abdur Rashid, Md. Abdus Salam, Sukanta Kumar Shill and Md. Kowsur Hasan, we found some ideas about replacement of coarse aggregate by brick aggregates. Again, in the paper "Performance and Properties of Structural Concrete Made with Recycled Concrete Aggregate by Ahmad Shayan and Aimin Xu", use of recycled concrete aggregate in structural concrete was described with its performance. Keeping those aspects in mind, this paper intends to further elaborate the performance of recycled brick chip aggregate and relate with the performance of concrete with different aggregates.

3. Experimental Procedure

3.1. Method of Mix Design

In our research, the Fineness Modulus (FM) method was followed to design the mix, as it is universally used a realistic method. Concrete was designed for 28 days compressive strength of **2500** psi. The preparation procedures were same but the aggregate material conditions varied from mix to mix. The aim of this experiment was to get a specific idea about the gaining of strength due to varying material conditions (stone chips, shingles, recycled concretes and brick chips). Laboratory tests were carried out to get the compressive strength of cement mortar and FM of sand, stone chips, shingles, recycled concretes and brick chips etc. During preparation, all the ingredients were brought to the specific standard condition as nearly as possible to ascertain the deviation of field condition from the standard condition.

3.2. Investigation of Materials

As we have seen, to design a concrete mix, information about the materials properties are required. Some of the information are directly used in design, some are required to conform to the minimum requirement demanded by the strength and durability restraint of concrete mix (to be designed). Sampling technique is adopted for material investigation purpose. To obtain representative value and to minimize sampling error, samples were taken from the storage to be used and several samples were collected to obtain an average value. Moreover, materials were in proper condition during testing, apparatus were in good shape and above all the person conducting the test knew what is to be done exactly. Standard and specified rules and instructions were carefully followed while testing the ingredient materials and it was remembered that accurate recording and manipulation of data is a necessity of utmost importance.

3.2.1. Cement

Type: Ordinary Portland Cement (Type 1 Cement), Seven Rings Cement
Specific gravity: 3 .15
Strength: The result of the compressive strength test of the cement used in the experiments is listed in tabular form below:

Table 1: Compressive Strength of Cement (28 Days)

Days	Specimen No	Strength Obtained (psi)	Strength Obtained (N/mm^2)	Average Strength Obtained (psi)
3	1	1919.80	13.24	**1875**
	2	1734.20	10.96	
	3	1969.10	13.58	
7	1	3517.70	24.26	**3360**
	2	2646.25	18.25	
	3	3920.80	27.04	
28	1	6232.79	42.98	**6120**
	2	6010.25	41.45	
	3	6120.52	42.21	

3.2.2. F.A. (Sand)

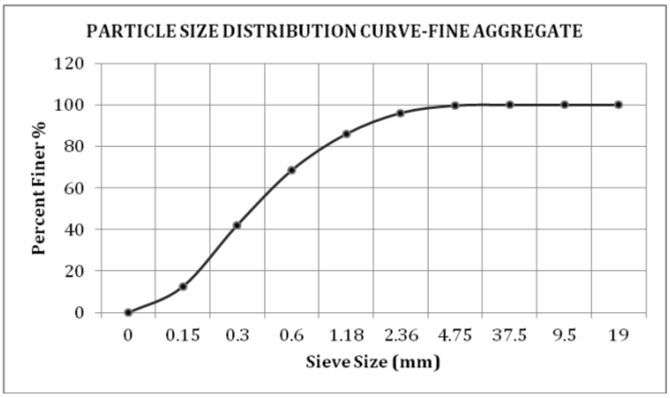
Bulk specific gravity: 2.77 (SSD), 2.73 (OD)
Bulk unit weight: 100 pcf
FM: 1.95

Table 2: Sieve Analysis of Fine Aggregate (Total Fine Aggregate=1000 gm)

Sieve Number	Sieve Opening (mm)	Materials Retained (gm)	% of Materials Retained	Cumulative %Materials Retained	Percent Finer
1.5"	37.5	0	0	0	100
¾"	19	0	0	0	100
3/8"	9.5	0	0	0	100
#4	4.75	3	0.3	0.3	99.7
#8	2.36	36	3.6	3.9	96.1
#16	1.18	101	10.1	14.0	86.0
#30	0.6	175	17.5	31.5	68.5
#50	0.3	264	26.4	57.9	42.1
#100	0.15	296	29.6	87.5	12.5
Pan	-	124		0	
∑		**999**		**195.1**	

So, FM of F.A.=195.1/100 = 1.951 = 1.95

Figure 1: Particle Size Distribution Curve of F.A



3.2.3 C.A.

Bulk specific gravity: 1.92 (SSD), 1.53 (OD)
Bulk unit weight: 100 pcf

Table 3: Sieve Analysis of Coarse Aggregate-Stone Chips (5000 gm)

Sieve Number	Sieve Opening (mm)	Materials Retained (gm)	% of Materials Retained	Cumulative % of Materials Retained	Percent Finer
1.5”	37.5	0	0	0	100
¾”	19	1200	24.02	24.02	75.98
3/8”	9.5	3463	69.32	93.34	6.66
#4	4.75	324	6.49	99.83	0.17
#8	2.36	5	0.1	99.93	0.07
#16	1.18	0	0	99.93	0.07
#30	0.6	0	0	99.93	0.07
#50	0.3	0	0	99.93	0.07
#100	0.15	0	0	99.93	0.07
Pan		4		0	
∑		**4996**		**716.84**	

FM of Stone Chips = 716.84/100 = 7.1684 = 7.17

Figure 2: Particle Size Distribution Curve of Stone Chips

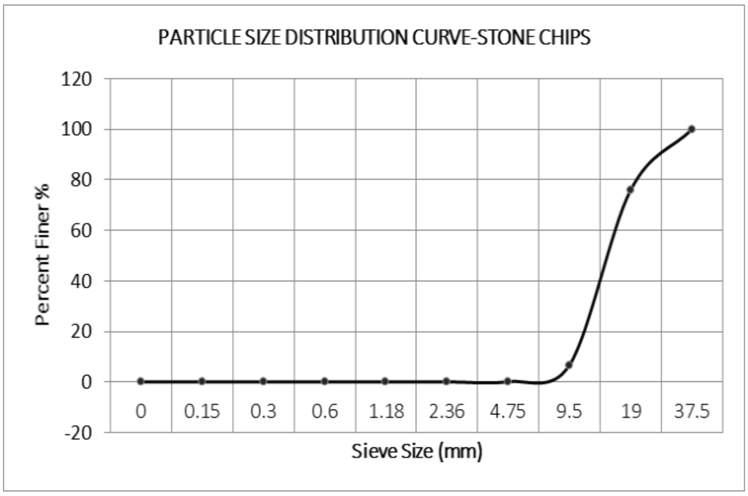


Table 4: Sieve Analysis of Coarse Aggregate-Shingles (5000 gm)

Sieve Number	Sieve Opening (mm)	Materials Retained (gm)	% of Materials Retained	Cumulative % of Materials Retained	Percent Finer
1.5”	37.5	0	0	0	100
¾”	19	1061.5	21.23	21.23	78.77
3/8”	9.5	3531.5	70.63	91.86	8.14
#4	4.75	331	6.62	98.48	1.52
#8	2.36	58.5	1.17	99.65	0.35
#16	1.18	10.5	0.21	99.86	0.14
#30	0.6	1	0.02	99.88	0.12
#50	0.3	0	0	99.88	0.12
#100	0.15	2	0.04	99.92	0.08
Pan		4		0	
∑		**5000**		**710.76**	

FM of Shingles = 710.76/100 = 7.1076 = 7.11

Figure 3: Particle Size Distribution Curve of Shingles.

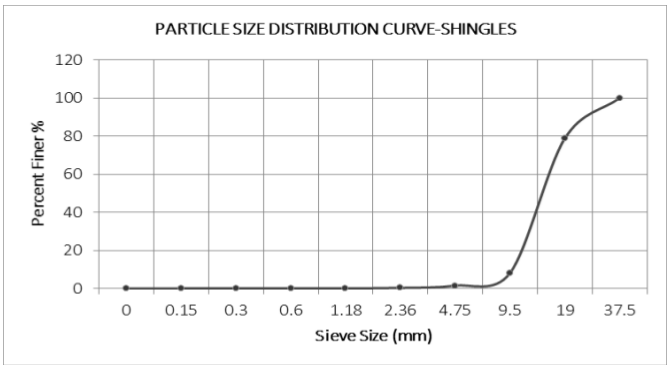


Table 5: Sieve Analysis of Coarse Aggregate-Recycled Concrete (5000 gm)

Sieve Number	Sieve Opening (mm)	Materials Retained (gm)	% of Materials Retained	Cumulative % of Materials Retained	Percent Finer
1.5”	37.5	0	0	0	100
¾”	19	1928	38.58	38.58	61.42
3/8”	9.5	2588	51.78	90.36	9.64
#4	4.75	435.5	8.71	99.07	0.93
#8	2.36	6	0.12	99.19	0.81
#16	1.18	1.5	0.03	99.22	0.78
#30	0.6	0	0	99.22	0.78
#50	0.3	14	0.28	99.50	0.50
#100	0.15	8	0.16	99.66	0.34
Pan		17		0	
∑		**4998**		**724.8**	

FM of Recycled Concrete= 724.80/100 = 7.2480 = 7.25

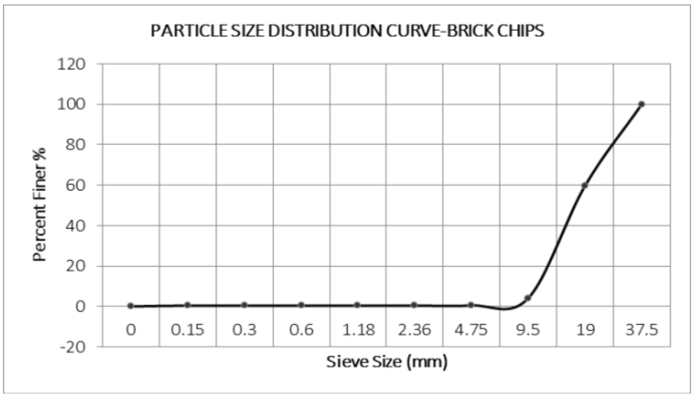
Figure 4: Particle Size Distribution Curve of Recycled Concrete

Table 6: Sieve Analysis of Coarse Aggregate-Brick Chips (5000 gm)

Sieve Number	Sieve Opening (mm)	Materials Retained (gm)	% of Materials Retained	Cumulative % of Materials Retained	Percent Finer
1.5”	37.5	0	0	0	100
¾”	19	2015	40.3	40.3	59.7
3/8”	9.5	2781	55.63	95.93	4.07
#4	4.75	180	3.6	99.53	0.47
#8	2.36	2	0.04	99.57	0.43
#16	1.18	1	0.02	99.59	0.41
#30	0.6	0	0	99.59	0.41
#50	0.3	0	0	99.59	0.41
#100	0.15	0	0	99.59	0.41
Pan	-	20		0	
∑		4999		733.69	

FM of Brick Chips = 733.69/100 = 7.3369 = 7.34

Figure 5: Particle Size Distribution Curve of Brick Chips



3.3. Mix Design Computation (FM Method)

3.3.1. Mix Design Considering Stone Chips as C.A.

Design a concrete mix for design compressive strength of **2500 psi** after 28 days from the following data:

Maximum size of C.A.	= 1 inch
Size of the F.A.	=1/16 to 3/16 inch
FM of C.A. (Stone Chips)	=**7.17**
FM of F.A.	=1.95
Moisture content of F.A. (sand)	=5%
Moisture content of C.A. (Stone Chips)	=6%
Shrinkage factor	=0.75
Hand worked concrete with desired slump of	=2 inch
Ordinary Portland Cement is to be used.	

From the graph of strength of concrete with cement/total aggregate above,
Combined FM, F_{com}= 5.17 and volume of compacted aggregate is 6 (for 2500 Psi strength and 1-inch C.A.)
Ratio of F.A. to be mixed with 1 unit of C.A.,

R= $\frac{Fc-Fcom}{Fcom-Ff}$ = (7.17-5.17)/(5.17-1.95) = 0.621

Therefore, in every 100 cft of combined aggregate, F.A. = 38 cft and C.A. = 62 cft
Loose volume of combined aggregates = 6/0.75 = 8 cft
So, quantity of F.A. = 8 x (0.621/1.621) = 3.065 cft
Quantity of C.A. = 8 x (1/1.621) = 4.935cft
Hence, the trail mix ratio is:

Cement	**F.A.**	**C.A.**
1	3.065	4.935

The bulking of F.A. is 5% and the bulking of C.A. is 6%
So, amount of F.A. = 3.065 x 1.05= 3.22 cft
And amount of C.A.= 4.935 x 1.06= 5.23 cft
Field Mix Ratio is:

Cement: F.A.: C.A.= 1: 3.22 : 5.23 = **1 : 3.50 : 5.50**

3.3.2. Mix Design Considering Shingles as C.A.

Design a concrete mix for design compressive strength of **2500 psi** after 28 days with all parameters same but FM of C.A. **(Shingles)** =**7.11**
Ratio of fine aggregate to be mixed with 1 unit of coarse aggregate,

R= $\frac{Fc - Fcom}{Fcom - Ff}$ = (7.11-5.17)/ (5.17-1.95) = 0.602

Therefore, in every 100 cft of combined aggregate, F.A. = 37.5 cft and C.A. = 62.5 cft
Loose volume of combined aggregates = 6/0.75 = 8 cft
So, quantity of F.A. = 8 x (0.602/1.602) = 3 cft
Quantity of C.A. = 8 x (1/1.602) = 5 cft
Hence, the trail mix ratio is:

Cement	**F.A.**	**C.A.**
1	3	5

The bulking of F.A. is 5% and the bulking of C.A. is 6%
So, amount of F.A. = 3 x 1.05= 3.15 cft
And amount of C.A. = 5 x 1.06= 5.3 cft
Field Mix Ratio is:
Cement: Fine Aggregate: Coarse Aggregate = 1: 3.15: 5.3 = **1:3.50:5.50**

3.3.3. Mix Design Considering Recycled Concrete as Coarse Aggregate

Design a concrete mix for design compressive strength of **2500 psi** after 28 days with all parameters same but FM of C.A. **(Recycled Concrete)** =**7.25**
Ratio of fine aggregate to be mixed with 1 unit of coarse aggregate,

R= $\frac{Fc - Fcom}{Fcom - Ff}$ = (7.25-5.17)/ (5.17-1.95) = 0.656

Therefore, in every 100 cft of combined aggregate, F.A. = 39.61 cft and C.A. = 60.39 cft
Loose volume of combined aggregates = 6/0.75 = 8 cft
So, quantity of F.A. = 8 x (0.656/1.656) = 3.169 cft
Quantity of C.A. = 8 x (1/1.656) = 4.831 cft
Hence, the trail mix ratio is:

Cement	**F.A.**	**C.A.**
1	3.169	4.831

So, amount of F.A. = 3.169 x 1.05= 3.327 cft
And amount of C.A. = 4.831 x 1.06= 5.121 cft
Field Mix Ratio is:
Cement: Fine Aggregate: Coarse Aggregate = 1: 3.327: 5.121 = **1:3.50:5**

3.3.4. Mix Design Considering Brick Chips as Coarse Aggregate

Design a concrete mix for design compressive strength of **2500 psi** after 28 days with all parameters same but FM of C.A. **(Brick Chips)** =**7.34**
Ratio of fine aggregate to be mixed with 1 unit of coarse aggregate,

R= $\frac{Fc-Fcom}{Fcom-Ff}$ = (7.34-5.17)/ (5.17-1.95) = 0.674

Therefore, in every 100 cft of combined aggregate, F.A. = 40.26 cft and C.A. = 59.74 cft
Loose volume of combined aggregates = 6/0.75 = 8 cft
So, quantity of F.A. = 8 x (0.674/1.674) = 3.221 cft
Quantity of C.A. = 8 x (1/1.674) = 4.779 cft
Hence, the trail mix ratio is:

Cement	**F.A.**	**C.A.**
1	3.221	4.779

So, amount of F.A. = 3.221 x 1.05= 3.382 cft
And amount of C.A. = 4.779 x 1.06= 5.065 cft
Field Mix Ratio: Cement: Fine Aggregate: Coarse Aggregate = 1: 3.382: 5.065 = **1:3.50:5**

4. Testing of Concrete

4.1. Preparation of Cylinder Specimens

The most common of all hardened concrete is compressive strength test, partly because it is an easy test to make, and partly because many, though not all, of the desirable characteristics of concrete are qualitatively related to its strength; but mainly because of the intrinsic importance of the compressive strength of concrete in construction. The test for compressive strength is so sensitive to variations in procedure that it must be carried out strictly according to standard procedures so that results from different testing sources are comparable. For these research program ASTM specifications was adopted. The normal compressive test specimen in a cylinder is usually 6 inches in diameter and 12 inches in length (length to diameter ratio of **2:1**).

4.3 Testing of Concrete Cylinder

Testing of hardened specimens involves two distinct operations:

(a) Capping the cylinders
(b) Crushing the cylinders

4.3.1. Capping the Cylinder

Cast cylinders usually have rough end surfaces (particularly the top surface) which are not plane or parallel. If tested in this condition, the apparent strength of the concrete would be considerably reduced because of stress concentrations that are introduced on loading. Convex ends will lead to lower measured strengths than concave ones. Therefore, it is required that the specimen ends must be plane within 0.002 inch. Ways to achieve plainness are:

(a) By grinding the ends, which is expensive and time consuming.
(b) By capping the ends of the cylinder.

Three different capping materials are permitted as per ASTM C617 and they are:

i. Stiff Portland cement paste for fresh specimen.
ii. High strength gypsum plaster for hardened cylinders.
iii. Sulfur mortar for hardened cylinders.

In this work, sulphur mortar was used as capping material. The sulphur mortar was prepared by heating it to about 130^0C and then was poured into lightly oiled steel capping plates. The cylinders were set into the sulphur in such a way that the caps ended up being about 2-inch-thick and were aligned so that the deviation of each caps ended from perpendicularly with the axis of specimen was less than 0.5°. The whole operation was in accordance with ASTM guidance. After capping the cylinders were ready for testing and were kept moist until tested.

4.3.2. Crushing the Cylinders (ASRM C39)

Before crushing the diameter of each cylinder was recorded. The tests were carried out in Universal Testing Machine (UTM) to determine the compressive strength of each cylinder. Two hardened bearing blocks were used, a solid one that the specimen, sited on, and a spherically sealed one that would bear on the upper surface (These blocks must be plane to within 0.001).

4.3.3 Test Results and Graphs

The results obtained from the testing of concrete in lab are tabulated and the graphs according to the results are described as below:

Table 7: Concrete Strength Using Brick Chips as Aggregate in Cylinder Test

Days	Specimen No	Strength Obtained (N/mm^2)	Strength Obtained (psi)	Average Strength Obtained (psi) (Rounded)
7	1	8.975	1301.375	**1100**
	2	7.810	1132.45	
	3	5.910	856.95	
14	1	7.702	1116.79	**1210**
	2	9.044	1311.38	
	3	8.324	1206.98	
28	1	12.180	1766.10	**1900**
	2	14.142	2050.59	
	3	13.010	1886.45	
90	1	19.860	2879.70	**2500**
	2	16.844	2442.38	
	3	15.036	2180.22	

Table 8: Concrete Strength Using Singles as Aggregate in Cylinder Test

Days	Specimen No	Strength Obtained (N/mm^2)	Strength Obtained (psi)	Average Strength Obtained (psi) (Rounded)
7	1	2.437	353.36	**350**
	2	2.456	356.12	
	3	2.318	336.11	
14	1	2.129	308.71	**400**
	2	3.249	471.11	
	3	2.999	434.86	
28	1	4.537	657.87	**635**
	2	5.058	733.41	
	3	3.537	512.87	
90	1	3.144	455.88	**555**
	2	4.417	640.47	
	3	3.925	569.13	

Table 9: Concrete Strength using Recycled Concrete in Cylinder Test

Days	Specimen No	Strength Obtained (N/mm²)	Strength Obtained (psi)	Average Strength Obtained (psi) (Rounded)
7	1	7.362	1067.49	**920**
	2	6.222	902.19	
	3	5.517	799.965	
14	1	8.638	1252.51	**1265**
	2	9.607	1393.02	
	3	7.961	1154.35	
28	1	11.39	1651.55	**1690**
	2	12.69	1840.05	
	3	10.95	1587.75	
90	1	10.40	1508.00	**1660**
	2	11.26	1632.70	
	3	12.696	1840.92	

Table 10: Concrete Strength using Stone Chips as Aggregate in Cylinder Test

Days	Specimen No	Strength Obtained (N/mm²)	Strength Obtained (psi)	Average Strength Rounded (psi)
7	1	11.06	1603.70	**1615**
	2	12.00	1740.00	
	3	10.41	1509.45	
14	1	13.39	1941.55	**1785**
	2	11.54	1673.30	
	3	12.03	1744.35	
28	1	12.62	1829.90	**2030**
	2	14.53	2106.85	
	3	14.88	2157.60	
90	1	18.45	2675.25	**2840**
	2	21.56	3126.20	
	3	18.84	2731.80	

Figure 6: Concrete Strength Curve for Different Duration using Stone Chips as Aggregate in Cylinder Test

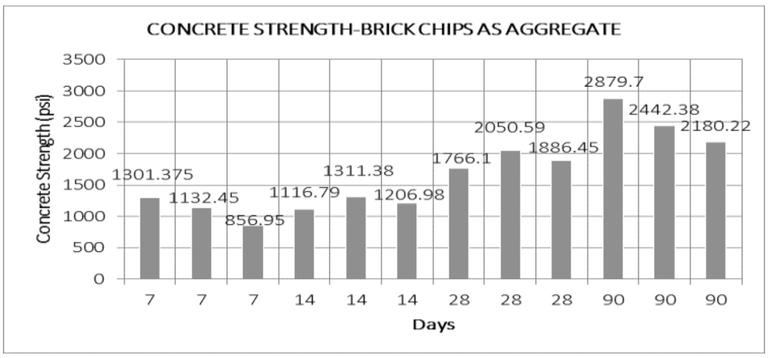


Figure 7: Concrete Strength Curve for Different Duration using Singles as Aggregate in Cylinder Test

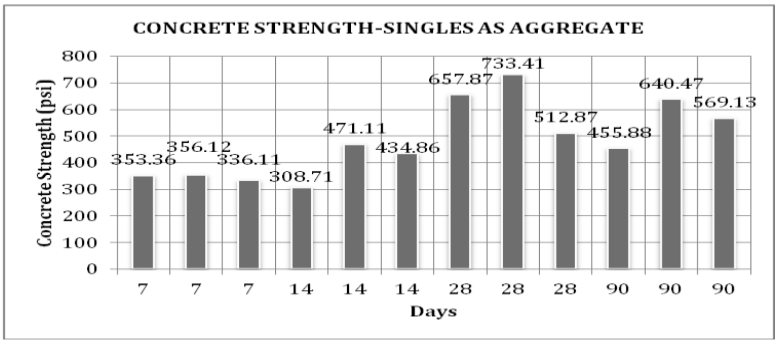


Figure 8: Concrete Strength Curve for Different Duration using Recycled Concrete as Aggregate in Cylinder Test

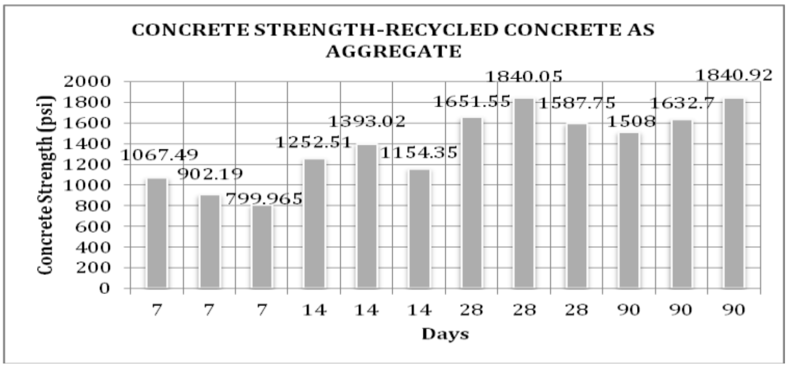


Figure 9: Concrete Strength Curve for Different Duration using Brick Chips as Aggregate in Cylinder Test

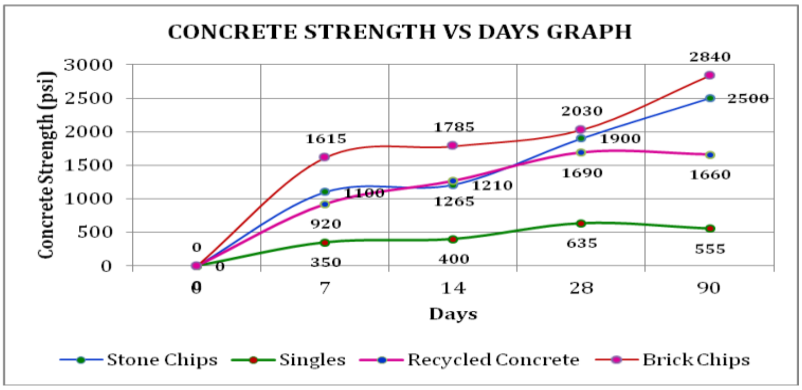
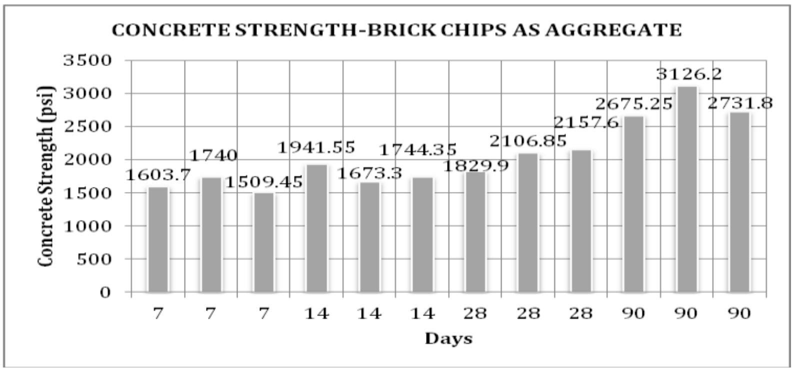


Figure 10: Strength VS Days Curve for Different Aggregates



5. Results and Discussions

5.1. Tested Results and Expected Results

From the test of cylinder specimens, it was found that at 28 days, only about 91% of the expected strength was obtained even through the cement was a very good one and the cube strength of cement mortar for 3, 7, and 28 days were very much satisfactory.

As seen from the test of cement it is very much clear that the concrete should have obtained a better strength from the cement's strength point of view. Our expectations were very high about the result and in the long run after a prolonged curing the designed strength was obtained. We designed the concrete for a compressive strength of 2500 psi at 28 days, but this strength was achieved after 90-150 days of curing. So suddenly we cannot say that the performance of the concrete is mainly due to the concrete alone, rather a lot of other factors involved, the aggregates properties and the testing conditions are also partly responsible for that which will be highlighted in the comments of the results. The failure pattern of the concrete was all through a combined failure. That means the failure plain was through the cement mortar and aggregates. The concrete was designed for 2500psi compressive strength at 28 days. It only reached 87% of its strength by continuous curing. The cement was very good and obtained about 6000 psi strength by 28 days, but the concrete did not. The ACI code specifications were established for broken stone aggregates, not broken bricks so the strength of concrete made of brick aggregates might be less than the stone aggregate concrete.

From the curing point of view, it is found that even if we do not cure concrete for certain gap initially for 7 to 14 days, but continue it after that for a prolonged period, the strength can be again increased to a satisfactory level. In our test we have found that even after 28days of not curing, if we start curing suddenly, the strength can be increased by 10 percent. After 28 days when the slope of achieving strength becomes almost parallel to the base, any further increase of strength is quite difficult. Hence, it is established that curing during first 28 days is very important. And again, a prolonged continuous curing of two to three months can greatly increase the 28 days strength by 10 to 15 percent. Like the results of other researches on recycled aggregate, the result shows that the recycled aggregate is not too far behind the other aggregates in properties and performance.

5.2. Findings from the Experiment Results

From the test results following findings can be stated:

1. The mix design was done by Fineness Method. This method is a rational procedure but may not give result suitable from workability and economy point of view.
2. The 7-day strength of shingles and brick chips has varied slight but in the case of stone chips and recycled aggregate the variation was noticeable.
3. The 14-day strength of three different samples of stone chips were very similar, but strength of samples of same aggregate (like brick chips, shingles and recycled aggregate) have fluctuated.
4. The 28-day strength of stone chips and brick chips has varied slight but in the case of shingles and recycled aggregate the variation was noticeable.
5. The 90-day strength of all samples varied with each other.
6. The compressive strength of stone and brick chips has increased gradually.
7. The compressive strength of shingles and recycled brick chips has increased gradually up to 28 days, but after 28 days the strength decreased.
8. Shingles gave the lowest compressive strength and the brick chips gave the maximum compressive strength throughout the whole period of testing.
9. In 7 days and 14 days compression test, there was only mortar failure in all types of sample.
10. But in 28 days and 90 days the samples of brick chips and stone chips showed combined failure but recycled aggregate and shingle samples showed mortar failure.

Therefore, from the result it can be assumed that the conventional methods of using brick chips and stone chips can be given with an additional method of using recycled aggregate provided it is well treated. In previous studies use of brick aggregates in place of coarse aggregate and performance of recycled aggregate was justified with water cement ratio and compressive strength. With the results of this research, the comparison of result parameters of different aggregates with recycled brick aggregate can be used in future studies to prove its credibility and feasibility to be used as a widely used aggregate.

5.3. Effect of Curing and Testing Conditions on the Strength of Concrete

5.3.1. Effect of Curing Conditions

Concrete gains its strength by the hydration of cement particles. Hydration of cement continues over a long period of time and only in the presence of adequate moisture with its rate being optimized at favourable temperature. Curing serves to preserve this essentially desirable environment against loss of moisture from concrete. So, it is not surprising that curing was given the place of prime importance in this project work. Though continuous curing is always desired, situations arise when interruption of curing operation becomes unavoidable. Therefore, the effect of both interrupted and uninterrupted curing conditions were investigated and following points can be listed as the findings from the investigation.

a. The water/cement ratio should strictly be maintained while concreting since this is very much essential to maintain a specific water content, otherwise it can either decrease strength or increase workability or vice versa. In our tested result we found that 87-91%was achieved at 28 days of continuous curing and it went up to 100% after a prolonged curing of 90-150 days.

b. Once cement is strong enough, the principal factors affecting the strength of concrete are the properties of aggregate, as the aggregate plays a vital role in ordinary strength concrete. The properties of aggregate, mainly the unit weight specific gravity and the fineness modulus are contributing to the strength of concrete.
c. From our experimental result we have found out that curing for a prolonged period of 150 days have increased the strength of 28 days to about 15%. This clearly indicates that, hydration is a long process and we can apply water to casted concrete for a long period of time.
d. It is again observed that even though we discontinued curing for a few days, but again curing after a short break could further increase the strength. Here it is important to mention that the rate of increase of strength is very high at the initial days after casting, which is for the first 7 to 14 days, and curve approaches to almost horizontal level after 28 days. So, the initial few weeks of curing is the most important factor in gaining strength.

5.3.2 Effect of Testing Conditions

Testing condition is a matter of the most important part for examining a concrete material in the laboratory. If we go through the procedure in a wrong way, there is all the possibilities to misinterpret the tested results. Strict adherences to the testing rules are very important for the following reasons:

a. The capacity layer which is put on the top and bottom of the cylinder specimen has to be flat and plain surface, as the ASTM specifies that the end surface of the specimen should be plain within .05 mm or .002 inch, as determined by a straight edge and a feeler gauge. Lack of plainness can lower the strength by one-third. The surface condition can also reduce the strength if it is concave or convex in shape.
b. The centering of the specimen head on the testing machine is very important getting the exact result of the test. Furthermore, the rate of loading of the testing machine is also a key factor for the accurate result of the test. ASTM standard C 39-72 stipulates a speed of 20 to 50 psi per second but permits the application of one half of the anticipated load at a higher rate than standard and the rest of the loading to be done at a lower rate until the specimen breaks, and this was not allowed strictly in our test.
c. Last of all the drying of the specimen before testing is also wedge action of the concrete particles to procedure fractional resistance to the failure of concrete greatly reduce for the presence of water, through this is not a usual fact as concrete with water many times in its life, but for testing purpose this can be taken into consideration.

6. Conclusion

In the experimented design and testing of a concrete mix for a strength of 2500 psi, it is observed that the effect of two important variables on strength, namely curing and quality control. As concrete failure can be actuated either by the crushing of coarse aggregate or by the mortar failure, strength of coarse aggregate plays an important role. ACI design method was strictly followed for proportioning the mix. Best effort was given to ensure SSD condition of aggregates, and proper mixing and preparation of cylinders. As water/cement ratio is the prime factor determining the concrete strength it was an effort to keep quantity of water (it was always remembered that strength is an inverse function of water/cement ratio) the same found from the computation. But for the results to be of practical worth workability of mix (suitable for building construction in our case) was given due attention too, it was always tried not to assist the gain of strength at the cost of workability (it may be recalled that workability increases with the increase in water content and vice versa). Hand mixing was used for concrete mixing and temping rod was used for compacting the mix according to the ASTM specification. Use of recycled aggregate can be considered as a method for our country because of its performance and economical input. But in our research extensive testing for its other parameters and conditions were not done which can be included in other researches to further strengthen its credibility as a widely used aggregate.

6.1 Scope of Future Study

Few scopes for further studies can be derived from the experience:

a. In the experiment it was clearly found that the aggregate property should have been tested for the confirmation of the aggregates effect on the strength of concrete. So in the future stone aggregate as well as brick aggregates can be simultaneously tested and the tested results can be put into the codes for future reference, especially for our country as we use khoa(broken brick chips) as coarse aggregate.
b. The results of different types of curing; like steam curing, water curing, sealed curing etc. can be tested. The cylinders can be tested as dry and wet specimen to get the variation in strength for those conditions.
c. As it was found that concrete cylinders failed completely with aggregates (combined failure), the aggregates crushing value, or the abrasion properties can be tested in future for the determination of the influence of aggregate properties on the strength of concrete.
d. An intensive and detailed study can be made to develop statistical patterns of strength variations among various curing conditions. Results of previous studies may help a great deal in this regard.

Last but not the least, a limiting value of strength in percentage of the desired strength can be put in the codes to use a concrete material for a construction purpose in the field after it has been tested in the laboratory. As for example, a concrete of 4000 psi design strength should not be used if say its laboratory strength is 75% or less which is 3000 psi at the end of 28 days otherwise testing will be a procedure only and the field condition will not be controlled.

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