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EVALUATING THE DURABILITY OF RECYCLED BRICK AGGREGATES AGAINST SULFATE ATTACK

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Abstract

The objective of this research study was to evaluate the long-lasting properties of concrete against sulfate action, comparing different level of recycled brick aggregate and to examine the feasibility of utilizing the brick as coarse aggregate in concrete. The procedures used to evaluate effects of sulfate attack involve variation in compressive strength, variation in weight, and visual assessment. Concrete cylinders were placed for the effect of sulfate attack in 6.0 % and 10.0 % of sulfate solution ($MgSO_4$) for 28.0, 56.0 & 84.0 days after ordinary water. Curing for 28.0 days, the compressive strength was measured for each specimen. The water-cement ratio 0.550 was used. It can be examined from the research study that the compressive strength of concrete significantly decline as the replacement of recycled brick aggregates rises. When the sulfate solution intensity rises, the concrete compressive strength reduces. Sulfate solution has an influence on concrete compressive strength after 56.0 days, and after 28.0 days of placing in 6.0 % and 10.0 % sulfate solution. In this research study, besides the percentage replacement of recycled brick aggregate concrete against sulfate attack did not have a fair efficiency as compared to the mechanical properties of normal concrete. The results of this research study clearly indicate that the gradual decline in compressive strength utilizing recycled brick as aggregate was more sensitive to the sulfate attack relative to conventional aggregate

Keywords: Compressive strength, Durability, Green concrete, Recycled brick aggregate, Replacement level, Sulfate attack, Sulfate solution (MgSO4).

1. Introduction

Concrete is a complex mixture of various parts that depend on the requirement. These concrete products are used at different proportions like 1:2:4 or 1:3:6 etc, which influence concrete strength exponentially. The first portion is cement in this ratio, the second portion is sand, and the third portion is coarse aggregate. This is famous that strength depends on the ratio of cement to aggregate, the mortar to aggregate bond, the W / C ratio and the aggregate gradation etc. Because most of them are interrelated, the aggregate function is not yet completely solved in concrete properties [1]. The volume of aggregates is up to 80% in concrete that are usually the outcome of raw material [2]. As the ordinary aggregate is declining faster, the concrete manufacturing industry is attempting another approaches. One of the viable approach is to recycle aggregates from destructed [3].

Not only in urban areas, it is inexpensive, but it also seeks for green approach. The use of recycled materials as aggregates in civil Engineering schemes is beneficial due to lower handling, transportation and quarrying costs and environmental effects [4]. The initiative of making concrete by using reused aggregate is gaining success gradually but definitely [5]. The estimated 60.0 % to 70.0 % of the destroyed concrete is used in sub base of road construction [6].

The recycling and demolition of waste is progressively becoming much more beneficial due to additional transport expenses and landfill fees [7].

According to surveys, concrete use is generally estimated at 2268 Kg per person per annum, equivalent to 17500 million for 7000 million citizens globally. The worldwide volume of concrete demolished is expected to reach between 2 and 3 billion tons [8].

In the 20th century, more research was conducted to assess the possibility of crushed brick as a concrete aggregate [9].

The application of broken brick aggregates has been systematically researched since 1928, primarily in the 1940s and 1950s.

In Europe, after the World War II, from the war era the leftover rubble was to be eliminated and introduced to the new structure. Recycling rubble factories were built, the profit would be twice: The rubble is removed, and the fresh concrete aggregate is provided. About 11.5 million m^3 of broken bricks were recorded to be produced by the end of 1955 with the development of one lakh and seventy five thousand residence units. The broken brick aggregate study has usually alert about its mechanical effects when it is used as coarse aggregate in concrete [10]. Until now, the study on brick aggregates has continued. It was shown that concrete can be made with broken brick aggregates for a wide range of applications [11].

The natural coarse aggregate decomposition especially in the vicinity of construction sites, and the rising requirement for aggregates by the construction industry further encourage the implementation of this latest idea of recycling technology [12]. The crushing resistance differs from 3.5 N/mm2 for normal soft facing bricks to 140 N/mm^2 for engineering clay bricks in case tested in the dry state. In general, breaking strength declines with increasing porosity, however strength is also affected by composition of clay and firing temperate [13]. Silica sand suitable for industrial use must not contain some limited proportion of

metallic elements. Since the size distribution of silica sand should be uniform, most of the industries do not satisfy the minimum requirements [14]. Lightweight concretes created with recycled ground distended polystyrene by proprietary technology of the school of Civil Engineering in Subotica [15].

Conversely, a research study is inadequate. The purpose of the research is to examine the effects of recycled brick aggregates on durability [16]. Significant study has been conducted to evaluate the behaviour of recycled aggregate concrete. Moreover, further study is necessary to make this methodology viable and practical. Therefore, research is currently in progress to establish this technology viable. One such attempt is the outcomes of the recent research identified here.

The main goals of this study are:

- To verify RBA's suitability as a feasible concrete aggregate source.
- To analyse and compare the compressive strength characteristics of concrete comprising recycled brick aggregates.
- To evaluate long-lasting properties such as compressive strength , durability, creep etc against sulfate attack of recycled brick aggregates concrete.

2. Materials and Methods

The materials used are:

- Ordinary Cement
- Coarse aggregate
- Fine aggregate (sand)
- RBA
- Portable Water (Water free from any impurities)

2.1. Fine aggregates

The local sand was used as fine aggregate and the local crush was used as coarse aggregate. This was obtained from Ring Road Peshawar, KPK, Pakistan.

2.2. Recycled brick aggregate

The RBA in this research work was sourced from demolished building sites as shown in Fig. 1. These bricks are first crushed by using Hammer to a size of 40mm or less then it is crushed by using crusher of PCSIR lab as shown in Fig. 2. Due to this the recycled aggregates of size 5.0 mm to 25.0 mm are obtained. These recycled aggregates are kept in the oven for 24 days and are dried at 105 ℃.

The different experiments such as sieve analysis, moisture content, specific gravity , density of aggregate is taken out on recycled aggregates. The aggregate sizes of recycled brick were used from 5 mm to 25 mm. Different aggregate characteristics such as specific gravity, aggregate sizes, moisture content, mixing ratio for preparing the samples should be known. Laboratory tests were conducted to find its various characteristics already define. The method is almost the same as the coarse aggregate method.

Fig. 1. Demolished building site.

Fig. 2. PCSIR lab crusher.

2.3. Cement

The common cement of code ASTM C 150 Type-1 was used. Cement used in examination was ML brand of Grade 53. Cement used in the examination was giving to the accompanying benchmarks.

- Pakistan PS 232.00-2008 (R)
- Standards of America ASTM C 150.00 Type-1
- Standards of British BS 12.00: 1996
- Standards of Europe EN 197.00-1/2000 CEM I 42.50 N/R

2.4. Coarse Aggregate

The local crush was used as coarse aggregate. This was obtained from Ring Road Peshawar, KPK, Pakistan.

2.5. Water

At SARHAD University Peshawar, tap water was used for the experimental job.

3. Research Methodology

To achieve the above objectives, the preceding activities are to be undertaken.

- Collect different material from different places i.e. Old Brick , Sand, Crush, Cement, and Water etc.
- After collecting material, like recycled bricks, was broken in a PCSIR Lab jaw crusher and the RBA was transformed in the PCSIR laboratory to the size of natural aggregate i.e. 5mm to 25mm. The recycled brick aggregate substitution was used by an interval of 0.0 %, 50.0 % and 100.0 % as presented in Table 1.
- For the mixing operation, ASTM C305 was used to prepare the specimens shown in Figs. 7-12. For the determination of compressive strength a total of 63 cylinders were casted.
- Different tests were carried out i.e. Specific gravity, Sieve Analysis, Water absorption test, SEM Test, Flexure strength test, Compressive strength test, etc.
- Significant facts regarding hydration of cement, development of hydration products and distribution, aggregates bond, is find out in scanning electron microscopy test.

- Find out the fresh and hardened concrete properties i.e. After 28.0 days find out the compressive strength of concrete cylinders having different level of recycled brick aggregate.
- For evaluation of sulfate attack, concrete cylinders will be placed in sulfate solution of 6.0 percent and
- 10.0 percent for 28.0 days, 56.0 & 84.0 days after curing in ordinary water for 28.0 days. The compressive strength was recorded for each cylinder at different duration.
- The procedures used to evaluate sulfate effects consist of weight changes, compressive strength changes, and visual reviews.
- Compare the outcome using a chart for various specimens as discussed above.

Table 1. Classification and % Level of RBA.

Mix	Classification	% Level of Recycled Bricks Aggregate
Substitution 1 (Recycle Brick Aggregate)	M_0	0.0 %
Substitution 2 (Recycle Brick Aggregate)	M_{50}	50.0%
Substitution 3 (Recycle Brick Aggregate)	M_{100}	100.0%

4. Mix Design

After mix design according to ACI 318, ratio 1 (Cement) : 2 (Sand) :3 (Coarse aggregate) was used for the cylinder preparation. The coarse aggregate is replaced by mass in different percentage by recycled bricks. The Recycled brick aggregate replacement ratio is 0.0 %, 50.0 % and 100.0 %. The amounts of material for concrete cylinders are shown in Table 2.

Table 2. Amounts of material for concrete cylinders

Type	Recycled brick aggregate % age	Cement [kg]	Fine Aggregate [kg]	Coarse Aggregate [kg]	Recycled brick [kg]	w/c = 0.550 Water [Litre]
M_0	0.0%	56.100	111.960	168.030	0.0	30.840
M_{50}	50.0%	56.100	111.960	84.030	84.030	30.840
M_{100}	100.0%	56.100	111.960	0.0	168.03	30.840

5. Material Properties.

By using graphs and table the outcome of the experimental work is shown. An experimental program aims are to evaluate the durability of recycled brick aggregate subjected to MgSO4 solution.

5.1. Gradation test

ASTM C136-05 procedure was used. The sieve Analysis of sand, coarse aggregate and recycled brick aggregate sample are shown in Tables 3 to 5 and Gradation curve are shown in Figs. 3, 4 and 5 correspondingly. The Fineness Modulus and Specific Gravity of Aggregate are shown in Table 6 and Table 7 correspondingly.

Table 3. Sand sieve analysis.

Sieve	Retained Weight [gm]	Retained Weight [%]	Passed Percent (%)	Cumulative Retained (%)	Min	Max	Remark
#4	0.00	0.00	100.00	0.00	95.0	100.0	✓
#8	2.930	0.5850	99.430	0.5830	80.0	100.0	✓
#16	65.50	13.070	86.380	13.630	50.0	85.0	✓
#30	189.50	37.870	48.540	51.465	25.0	60.0	Not ok
#50	190.40	38.0770	10.470	89.540	5.0	30.0	✓
#100	48.350	9.6670	0.802	99.202	0.0	10.0	✓
Pan	4.03	0.802	0.00	100.00			

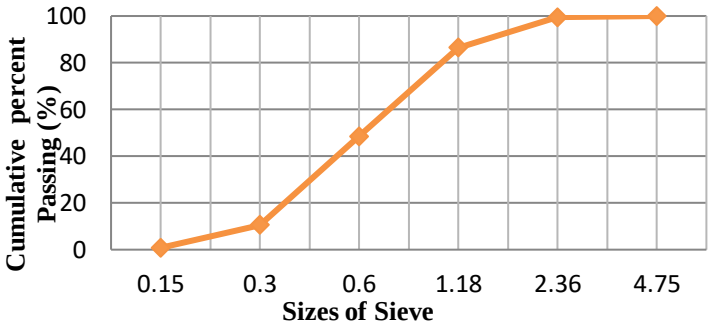

Fig. 3. Sand gradation curve.

Table 4. Coarse aggregate sieve analysis.

Sieve (mm)	Retained Weight [gm]	Retained Weight [%]	Passed Percent (%)	Cumulative Retained (%)	Min	Max	Remark
25.0	0.00	0.00	100.0	0.00	100.0	100.0	✓
19.0	1660.01	55.340	44.680	55.340	90.0	100.0	Not ok
12.5	505.801	16.880	27.830	72.201	20.0	55.0	✓
9.50	710.101	23.680	4.150	95.880	0.0	15.0	✓
4.75	124.030	4.140	0.00	100.00	0.0	5.00	✓
Pan	0.091	0.00	0.00	100.00			

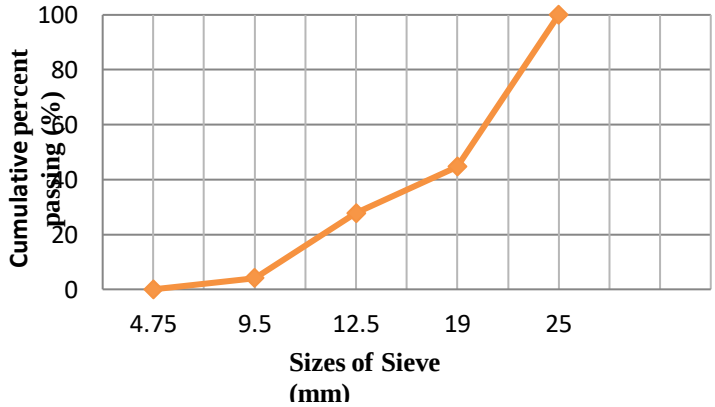

Fig. 4. Coarse aggregate gradation curve.

Table 5. Brick aggregate sieve analysis.

Sieve (mm)	Retained Weight [gm]	Retained Weight [%]	Passed Percent (%)	Cumulative Retained (%)	Min	Max	Remark
25.0	0.00	0.00	100.0	0.00	100.0	100.0	✓
19.0	1987.57	66.260	33.76	66.260	90.0	100.0	Not ok
12.5	371.360	12.379	21.38	78.640	20.0	55.0	✓
9.50	539.020	17.968	3.420	96.620	0.0	15.0	✓
4.75	102.090	3.4028	0.00	100.00	0.0	5.0	✓
Pan	0.0810	0.0040	0.00	100.00			

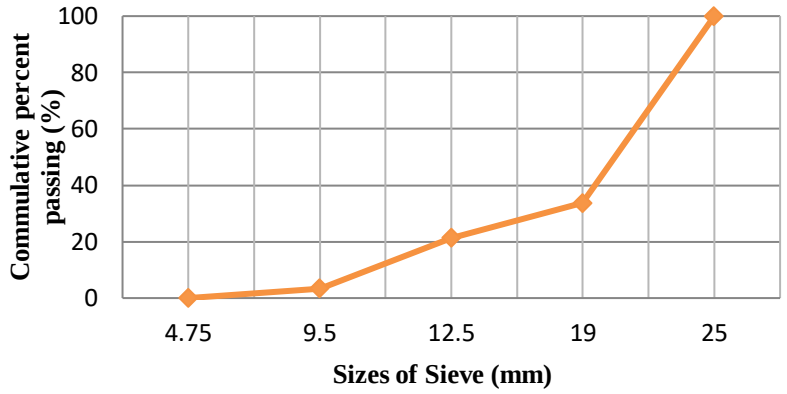

Fig. 5. Brick aggregate gradation curve.

Table 6. Fineness modulus of aggregate.

Type of Aggregate	Fineness modulus	Standard limits
Fine aggregate	2.550	2.30 - 3.10
Coarse aggregate	3.240	3.10 - 6.50
Recycled brick aggregate	3.420	3.10- 6.50

5.2. Aggregate sample specific gravity and absorption

ASTM C128 procedure was used for fine aggregate and ASTM C127 procedure fine aggregate and ASTM C127 procedure was used for both coarse and recycled brick aggregate.

Table 7. Specific gravity of aggregate.

Type of Aggregate	Specific Gravity	Absorption
Fine aggregate	2.540	0.40%
Coarse aggregate	2.580	1.150%
Recycled brick aggregate	1.980	18.130%

5.3. Fresh properties of concrete (Slump Test ASTM C-143)

ASTM C143 procedure was used for slump test. Table 8 and Fig. 6 illustrate that the value of slump reduces quickly, by increasing percent replacement of recycled brick aggregate in concrete. The main reason for reducing slump value of recycled brick aggregate is greater water absorption.

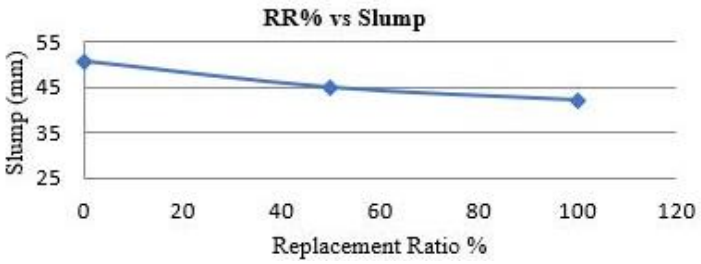

Fig. 6. slump value vs. replacement ratio.

Table 8. concrete sample slump value.

Replacement ratio (RR %)	Slump (mm)
0%	50.8
50%	45
100%	42.2

5.4. Casting and curing of concrete specimens

The procedure proposed by ASTM C39 / M is commonly used to determine the concrete sample's compressive strength. In this experiment, compressive force is applied into the concrete cylinder until the cylinder collapse completely.

Fig. 7. Casting of cylinders.

Fig. 8. Cylinder (0% RBA).

Fig. 9. Cylinder (50% RBA).

Fig. 10. Cylinder (100% RBA).

Fig. 11 . Curing tank.

Fig. 12 . Sulphate bath.

- For sulfate attack evaluation, concrete cylinders will be placed in sulfate solution of 6.0 percent and 10.0 percent for 28.0, 56.0 & 84.0 days after curing in ordinary water for 28 days. The compressive strength was recorded for all cylinder.
- The procedures used to evaluate sulfate effects consist of weight changes, compressive strength changes and visual reviews.

5.5. Results and discussion

Table 9 and Fig. 13 illustrate the outcomes of compressive strength of concrete samples and Table 11, and Fig. 15 illustrate the outcomes of weight variation of concrete samples after being placed in 6% sulfate solution. When the replacement percentage of recycled coarse aggregate rises, the compressive strength reduces. Strength is reduced as the harder material is replaced with softer material.

Table 9. Comparative statement of compressive strength at 6.0 % sulfate solution.

Type	28 days ordinary waters curing	Sulfate water curing					
		56.0 Days	% Loss	84.0 Days	% Loss	112.0 Days	%Loss
M_0	22.315	22.189	0.570 %	20.633	7.530 %	19.280	13.610 %
M_{50}	17.312	**16.590**	4.170 %	14.770	14.690 %	12.710	26.580 %
M_{100}	15.826	15.270	3.510 %	13.252	16.260 %	11.531	27.140 %

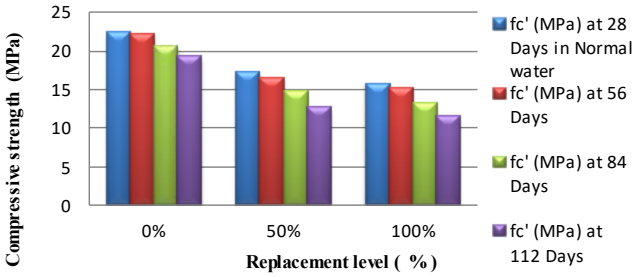

Fig. 13. Comparative statement of compressive strength at 6.0 % sulfate solution.

Table 10 and Fig. 14 illustrate the outcomes of compressive strength of concrete samples and Table 11, and Fig. 15 illustrate the outcomes of weight variation of concrete samples after being placed in 10% sulfate solution. When the replacement proportion of recycled coarse aggregate rises, the compressive strength decreases, also as the concentration of sulfate solution rises the compressive strength was reduced.

Table 10. Comparative statement of compressive strength at 10.0 % sulfate solution.

Type	28 days ordinary waters curing	Sulfate water curing					
		56.0 Days	% Loss	84.0 Days	% Loss	112.0 Days	%Loss
M_0	22.315	21.791	2.350 %	19.826	11.160 %	18.403	17.540%
M_{50}	17.312	16.113	6.920 %	14.165	18.140 %	11.787	31.10%
M_{100}	15.826	14.533	8.160 %	12.264	22.60 %	10.480	33.77%

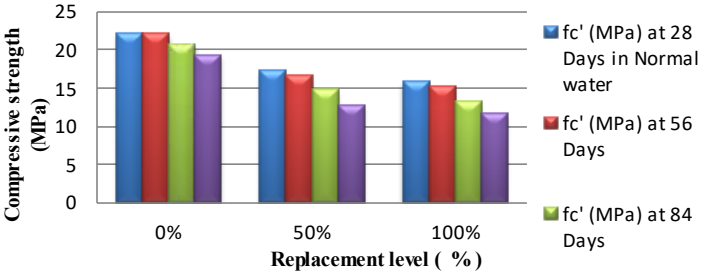

Fig. 14. Comparative statement of compressive strength at 10.0 % sulfate solution.

Table 11. Comparative statement at 6.0 % sulfate solution.

Type	28 days ordinary waters curing	Sulfate water curing					
		56.0 Days	% Loss	84.0 Days	% Loss	112.0 Days	%Loss
M_0	13.701	13.520	0.660 %	13.420	1.400 %	13.077	3.850 %
M_{50}	11.940	11.860	0.670 %	11.620	2.680 %	11.570	3.100 %
M_{100}	11.201	10.100	1.870 %	10.900	2.770 %	10.521	6.160 %

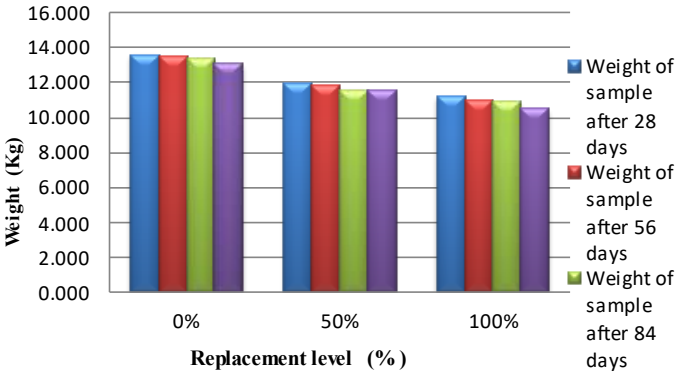

Fig. 15. Comparative statement at 6.0 % sulfate solution.

Table 12. Comparative statement at 10.0 % sulfate solution.

Type	28 days ordinary waters curing	Sulfate water curing					
		56.0 Days	% Loss	84.0 Days	% Loss	112.0 Days	%Loss
M_0	13.701	13.451	1.100 %	13.311	2.130 %	12.991	4.490 %
M_{50}	11.940	11.821	0.920 %	11.551	3.190 %	11.421	4.270 %
M_{100}	11.201	10.801	3.570 %	10.681	4.640 %	10.391	7.230 %

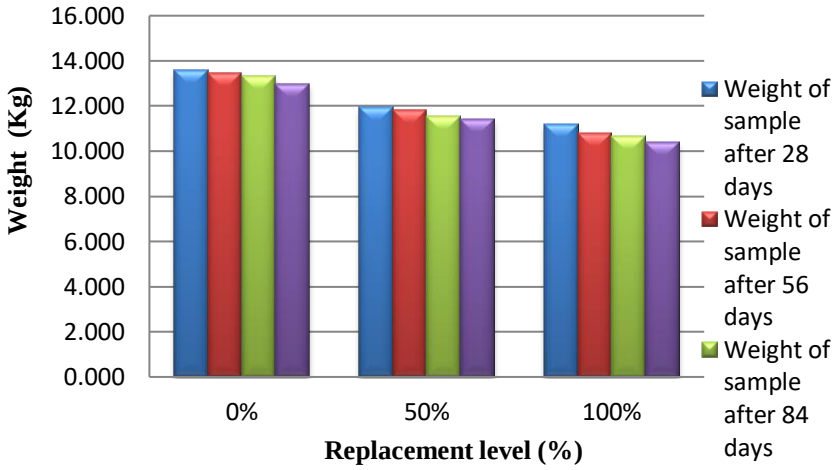

Fig. 16. Comparative statement at 10.0 % sulfate solution.

5.6. Sulphate effect on the flexural strength

Table 13 illustrate the outcomes of Flexural strength of concrete samples after being placed in 10% sulfate solution. When the replacement percentage of recycled coarse aggregate rises, the flexural strength increases.

Table 13. Comparative statement of flexural strength at 10.0 % sulfate solution.

Type	Replacement Level				
		56.0 Days	% Loss	84.0 Days	% Loss
M_0	0%	790.333	0	804.01	0.0%
M_{50}	50%	793.666	0.4%	809.33	0.7%
M_{100}	100%	802.666	1.1%	815.33	1.4%

6. Scanning Electron Microscopic Study of Sample

For a number of cylinders containing 0.0%, 50.0% and 100.0% of recycled brick aggregate Used SEM tests after 56 days. This test was carried out in the laboratory of physics department at University of Peshawar. The succeeding figure shows different arrangements for micro silt, silica gel (C-S-H) and recycled brick aggregate. Figure 17 shows the microstructures of mixtures having 0 percent, 50 percent and 100 percent recycled brick aggregate. The Whitish substance reveals

powdery bright material of magnesium sulfates. SEM study of sample containing 0%, 50%, and 100% of RBA.

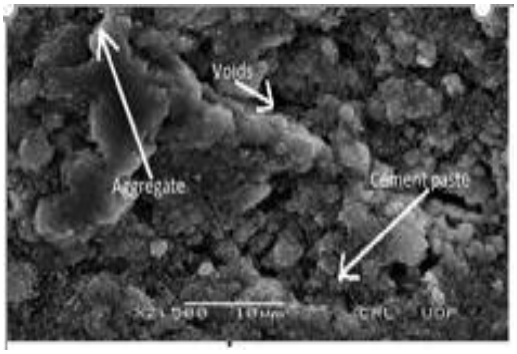

Fig. 17. 0 % RBC .

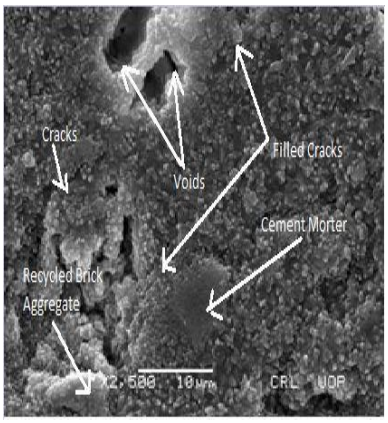

Fig. 18. 50 % RBC.

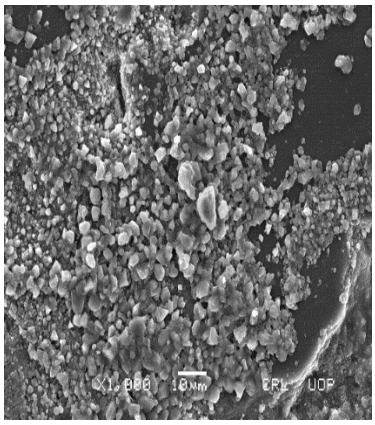

Fig. 19. 100 % RBC.

7. Conclusions

The recommendations of the research work can be concluded below:

- The workability of concrete that contains recycled brick as an aggregate is moderately less than the workability of ordinary aggregate concrete.
- Research work reveals that the concrete compressive strength reduces as the percentage of recycled brick aggregate rises, the reduction in compressive strength for replacement ratio (0.0 %, 50.0 %, and 100.0 %) was (17.540 %, 31.10%, 33.77 %) correspondingly.
- As the amount of sulfate solution raises, the concrete compressive strength reduces.
- The reduction in compressive strength was (13.610 %, 26.580 % and 27.140 %) for replacement ratio (0.0 %, 50.0 % and 100.0 %) respectively after 84.0 days of placing in sulfate solution of 6.0 %.
- The reduction in compressive strength was (17.540%, 31.10% and 33.77%) for replacement ratio (0.0 %, 50.0 % and 100.0 %) respectively after 84.0 days of placing in sulfate solution of 10.0 %.

- The results clearly show that concrete containing recycled bricks as aggregate have comparatively lesser strength than concrete having natural aggregate.
- The concrete containing recycled bricks as aggregate have comparatively lesser durability than concrete containing natural aggregate.
- The scanning electron microscope study demonstrates that as the recycled brick aggregate amount increases, the sulfate attack increase. This is because of the increase in concrete pores. Also increase in bricks water absorption capacity increases the sulphate attack on concrete.
- While to get the required compressive strength, relative to natural aggregate concrete, the greater quantity of cement and a lower W/C ratio was required for recycled brick aggregate concrete.

Acknowledgment

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Abbreviations

ASTM	American Society for Testing and Materials
PCSIR	Pakistan Council of Scientific and Industrial Research
RBA	Recycled Brick Aggregate
SEM	Scanning Electron Microscopic Study

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