Structural Engineering and Mechanics, *Vol. 47, No. 4 (2013) 545-557*
DOI: http://dx.doi.org/10.12989/sem.2013.47.4.545

Experimental investigation on the use of recycled aggregates in producing concrete

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(Received July 28, 2012, Revised August 12, 2013, Accepted August 16, 2013)

Abstract. Disposal of construction wastes poses major challenge to the municipal administration in the developing countries. At the same time new developments in these countries are unscrupulously exploiting the natural resources. The sustainable development requires judicious and careful utilization of natural resources. In this context, reuse of construction and demolition waste can save the global natural resources to greater extent. In this work the bricks and concrete waste from construction sites were crushed to the desired sizes and mixed in various proportions to study its properties in the concrete both in fresh and hardened states. Six mixes of natural and recycled aggregates were used to make the coarse aggregates for the concrete. From each mix nine cylinders were cast, which were tested at 7,14 and 28 days. The properties of concrete with recycled aggregates were compared with the control mix having natural aggregates. The nominal ratio of cement sand and coarse aggregates were kept at 1:2:4 by weight for all mixes. The tests have shown that concrete with recycled aggregates made from old concrete and brick bats provide greater opportunities for reuse of construction wastes in concrete.

Keywords: sustainable development; concrete; construction wastes; recycled aggregates

1. Introduction

1.1 Literature review

Sustainable Built Environment (SBE) requires resource conservation in the design, construction and maintenance stages of physical development. The three major resources normally used in the built environment include material, water and energy. The conservation of all these resources demand to apply the principles of 3R (Reduce, Reuse and Recycle) in the construction industry as well. The reuse of recycled concrete is thus becoming an economically and environmentally viable option for resource conservation in the construction industry. The economic gains in short term

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http://www.techno-press.org/?journal=sem&subpage=8 ISSN: 1225-4568 (Print), 1598-6217 (Online)

may not be very promising as the transportation, handling, segregation and crushing as well as gradation of the recycled aggregates involve additional costs, but its environmental gains in the form of low carbon emission, conservation of natural resources, reuse of waste material and low global warming impact of construction activities may be of high significance in times to come. That is why the Life Cycle Assessment (LCA) is becoming more powerful tool for the design and construction & of new infrastructure. Life Cycle Assessment (LCA) is a method for analyzing and assessing the environmental impact of a material, product or service throughout its entire life cycle, usually from the acquisition of raw materials to final disposal. The general categories of environmental impacts to be considered in an LCA include resource use, human health and ecological consequences (Blengini 2009). The reuse of recycled aggregates ultimately leads to low embodied energy of the resource used in construction as concrete is the major construction material and coarse aggregates constitute 70-80% of concrete.

Construction and Demolition Wastes (CDW) constitute 40% of the total waste generated in the world. According to definition of US EPA (1998) "Construction and Demolition Wastes (CDW) are waste material produced in the process of construction, renovation and demolition of structures". The structures include residential, non residential buildings, roads & bridges of all types. The typical components of C&D wastes are concrete, bricks, asphalt, gypsum wall boards, metal and woods. The CDW are increasing in all parts of the world due to enhanced construction activities on one hand and renovations, refurbishments of the existing physical infrastructure on the other hand.

The Gulf Cooperation Countries (GCC) produces 120 million tons of solid waste every year in which about 15% is construction wastes (Gulf today, 2010). In Dubai Municipality alone C&D wastes accounts for 75% of the daily solid wastes of 10,000 tons daily. Kartam *et al.* (2004), AlNaser (2007) Kayali *et al.* discussed the current status of construction and demolition waste disposal systems, alternative solutions to manage and control this waste in an economical, efficient and safe way and the available industrial waste products that can be used in making sustainable concrete and their relevance to the Middle East and other parts of the world. Galbraith (2008) outlined the role of structural design in sustainable buildings and its implication within the Gulf region. Gilpin *et al.* (2004) explored the opportunities for reusing the recycled aggregates from asphalt concrete and cement concrete in the new concrete construction. The annual volume of CDW in Hong Kong has crossed 14 million tons. The Govt. of Hong Kong has formulated two sets of specification for use of recycled aggregates in construction activities (WBHK, 2002). Similarly about 200 million tons of rubble from the construction industry and building demolition is produced annually in the European Union (EU). Fonteboa *et al.* (2005), checked the different rheological properties of concrete incorporating various mix proportioning of the recycled aggregates. They observed that recycled concrete aggregates in Spain are favorably comparable with the natural aggregates in terms of their physical properties and strength parameters. Jimeniz *et al.* (2008) worked on use of CDW as granular material in sub base construction of unbound roads for various traffic loads. They used various forms of recycled material such as mixed debris, recycled concrete aggregates etc. They reported that if good level of quality control is exercised, recycled concrete aggregates can give better results for unbound roads. Akash *et al.* (2007) studied the effects of recycled aggregates on the properties of fresh and hardened concrete and recommended to create awareness, governmental support and development of specifications/codes for reusing these aggregates in the developing countries.

The use of recycled aggregates from CDW is becoming a popular option in many developing countries of Asia, mainly due to the initiatives of the respective Governments. In Kuwait, Al-

Mutairi and Haque (2003) used old demolished concrete to replace 50 and 100% of the coarse aggregate and seawater to replace 25, 50 and 100% of the tap water in a standard concrete mix having moderate target strength. The recycled concrete was cured in seawater for a period of 28 days. The results indicated that even with 100% usage of recycled concrete aggregate, design strength of 35 MPa was attainable. Highest concrete strength was obtained when the mixing water consisted of a blend of 25% seawater and 75% tap water. Al-Harthy *et al*. (2007) conducted laboratory tests to examine the strength and durability of recycled aggregate concrete. The results showed that concrete strength is enhanced with the replacement of normal aggregates by recycled aggregate content of up to 30%, thereafter the strength decreases with further increase in recycled aggregate. Fong *et al.* (2004) showed that under normal water temperature, steam curing has increased the early strengths but reduced the long-term strengths for all normal and recycled aggregate concretes. Chen *et al.* (2003) used the construction rubbles including bricks and tiles as replacement to aggregates in various proportions. Poon *et al.* (2004) used the recycled aggregates in the construction of concrete blocks and bricks. Michael *et al.* (2011) studied the effects of low grade recycled concrete with mineral admixtures on the mechanical and environmental performance of concrete.

American Concrete Institute (ACI) has focused on reuse of hardened concrete. The Recycled Concrete Aggregates (RCA) contain crushed sound and clean concrete by 95% of the total weight of concrete and contamination of 1% or less. The brick contents in RCA have to be limited to 0.5% of the total weight of concrete. The use of RCA has been mainly recommended for footpaths, kerbs, sideways, gutter etc.

The mix proportioning of recycled aggregates require detailed analysis of the aggregates and its physical and chemical properties. Bairagi *et al.* (2003) studied the behavior of fresh and hardened concrete for various mix proportions of recycled concrete and recommended empirical relations for moduli of elasticity and rapture of concrete.

Many researchers tried to use finer material and construction wastes as replacement for sand and fine aggregates. Wang *et al.* (2012) used Taiwan-made recycled mineral admixture including fly ash, slag, glass sand and rubber powder etc, as replacements for fine aggregates in concrete to produce light weight concrete. They observed that the light weight concrete prepared with the recycled fine aggregates (green building material) yielded good compressive strength and other properties in fresh and hardened forms as compared to normal weight concrete.

Sirin *et al.* (2013) reported that around 20 million tons of construction waste is generated at Qatar due to construction boom. They used the Reclaimed Asphalt Pavement (RAP) in the construction of road bases and sub bases. Different combinations were prepared and tested. The values were compared to Qatar’s Construction Specification (QCS). However the results showed poor performance of the RAP as compared to the QCS. The authors recommended further research to explore the possibilities of reuse of old concrete and asphalt as aggregates for concrete.

Sunawane and Pimplikar (2013) studied the properties of recycled aggregates and compare it with the natural aggregates. The basic mechanical properties like compressive strength, flexural strength and workability were tested. They reported that use of recycled aggregates up to 30% doesn’t affect the functional properties of concrete.

Akbari *et al.* (2011), used various proportions of recycled aggregates in concrete and checked its slump, compressive strength and flexural strength. They have reduction in these properties of recycled aggregates in concrete, particularly beyond 25% addition of recycled aggregates. There is no well established procedure for the mix design of the recycled concrete aggregates, as the variation in the properties of waste material makes it difficult to standardize the various mix design

Table 1 Sector-wise MSW generation of Islamabad Pakistan

No	Sector	Amount of waste Tons/day	No	Sector	Amount of waste Tons/day
1	E-8	1.2	11	G-7	20.7
2	E-9	2.7	12	G-8	12.2
3	F-5	14.2	13	G-9	5.7
4	F-6	11.2	14	G-10	12.5
5	F-7 &E-7	19.3	15	G-11	5.7
6	F-8	23.6	16	I-8/H-8	46.3
7	F-10	10.6	17	I-9/H-9	7.2
8	F-11	6.1	18	I-10	37.1
9	G-5	1.3	19	I-11	85.8
10	G-6	82.8		Total	422.50

Source: *Waste Amount Survey in Islamabad, JICA/EPA*

Table 2 Details of MSW generation on the basis of various studies

No	Source of study	Year	Daily waste generation (tons)	Year	Daily waste generation (tons)
1	JICA	2004	422.50	2011	636
2	CAGP	2006	425.751	2011	571
3	Present study	2011		2011	866
4	CDA assessment	2011		2011	600
	Average daily solid waste			668.25	

Source: *Waste Amount Survey in Islamabad, JICA/EPA*

parameters. Usually trail mixes are carried out to reach at the desired strength. However efforts have been made by the researchers to develop some design standards and procedures for the mix proportioning of the recycled aggregates concrete. Park *et al.* (2013) have developed genetic algorithm incorporating the statistical data from the earlier studies on the recycled aggregates concrete. The neural network model was used to develop the desired performance level of recycled aggregates concrete measured in terms of slump, density, strength, elastic modulus, carbonation resistance, price and carbon dioxide emission etc. The proposed algorithm produced various mix options for the concrete to achieve the desired strength.

This research work has been started with the motivation to explore the opportunities for reuse of recycled concrete aggregates in new concrete. Various forms of recycled aggregates of concrete and bricks have been used in different proportions with the new natural aggregates and its properties in both the fresh and hardened states have been studied.

1.2 Construction and demolition wastes at local level

The construction activities in Pakistan have been increased substantially over the last one decade. The reconstruction and restoration of infrastructure and housing units damaged due natural disasters like earthquakes and floods on one hand and extensive investment in the housing sector at the other hand has given big impetus to the construction industry of Pakistan.

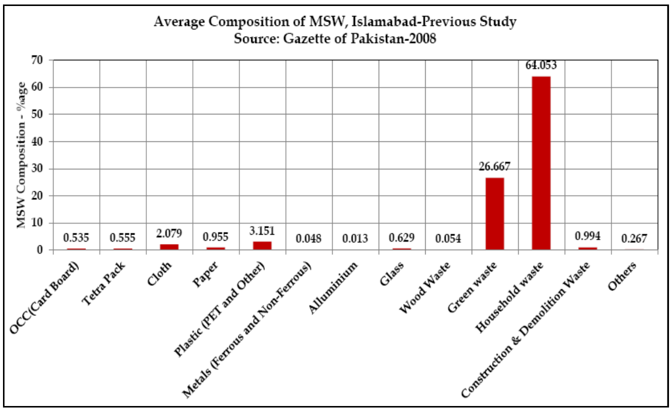

Fig. 1 Distribution of MSW in Islamabad Pakistan (Gazette of Pakistan, 2008)

The Municipal Solid Waste (MSW) collected from various sectors in the capital city of Islamabad Pakistan is shown in Table 1 and the daily MSW generation as reported in various studies is given in Table 2 (JICA/EPA, 2010). On the basis of assessed growth rate, the SWM generation of Islamabad will increase to 2689 tons per day by year 2040. The composition of the MSW in Islamabad Pakistan is given in Fig. 1. According to these estimates, the CDW in Islamabad is about 10% of the total wastes generated in the city. But this volume has increased since last many years due to increase in the construction and demolition activities in the city.

2. Experimental program

2.1 Cement

Ordinary Portland Cement (OPC) of type-I has been used in the research work.

2.2 Recycled aggregates

Two types of recycled aggregates from construction and demolition wastes i.e., bricks and concrete have been used in the tests. The aggregates have been crushed to the desired maximum sizes of 19 mm (3/4in) down by crushers. The gradation of the recycled aggregates is shown in Table 3, for bricks and Table 4 for Recycled Concrete Aggregates (RCA). For fine aggregates, natural sand from local source was used having a fineness modulus of 2.20.

2.3 Natural aggregates

Natural lime stone aggregates from the local sources were used. All aggregates were washed and cleaned before use in the laboratory.

2.4 Mix proportioning of concrete

For concrete mix design, the nominal ratio of 1:2:4 was used by weight. This ratio is the

Table 3 Gradation of recycled brick aggregates after crushing

Sieve size	Mass retained (gms)	Retained (%)	Cumulative Passing (%)	Cumulative retained (%)
1in(25mm)	78	0.78	99.22	0.78
¾ in (19mm)	1136	11.36	87.86	12.14
½ in (12mm)	6436	64.36	23.5	76.50
3/8 in (9mm)	1281	12.81	10.69	89.31
#4 (6mm)	986	9.86	0.83	99.71
Pan	83	0.83	0	

Table 4 Gradation of recycled brick aggregates after crushing

Sieve size	Mass retained (gms)	Retained (%)	Cumulative Passing (%)	Cumulative retained (%)
1in(25mm)	120	1.20	98.80	1.20
¾ in (19mm)	1244	12.44	86.36	13.64
½ in (12mm)	7250	72.50	13.86	86.14
3/8 in (9mm)	1031	10.31	3.55	96.45
#4 (6mm)	301	3.01	0.83	99.46
Pan	53	0.53		

commonly used mixed proportioning ratio in the local construction works in most of the construction components of ordinary nature such as foundations, beams, columns and slabs. In controlled mix, natural aggregates were used. The water cement ratio was kept constant at 0.7 to check the workability and slump of concrete for constant volume of water per batch of concrete.

2.4.1 Mix proportioning of natural recycled concrete and recycled bricks aggregates

Three mixes of aggregates from natural, recycled concrete and recycled bricks aggregates were used. In NRB-1, equal proportions of three types of aggregates have been used i.e., (1:1:1). Where as in NRB-2, the recycled brick aggregates have been reduced to half (1:1:0.5). In NRB-3, the contents of recycled concrete aggregates have been doubled of the natural aggregates and brick have been used half of the natural aggregates i.e. (1:2:0.5). From each mix, nine cylinders of size 300mm x 150mm have been cast. The water cement ratio was kept constant at 0.70. However for NRB-1, there was no apparent slump and the w/c ratio was increased to 0.80.

2.4.2 Mix proportioning of natural recycled concrete aggregates

In second group, three mixes were used, in which natural and recycled concrete aggregates were used with no brick aggregates. In NR-1, equal proportions of natural and recycled aggregates have been used. In NR-2, contents of natural aggregates have been doubled, whereas in NR-3, contents of recycled aggregates have been doubled. Nine cylinders were cost from each and the water cement ration was kept as 0.70. The slump was measured as constant w/c ratio.

2.4.3 Mix proportioning of controlled mix

In control mix, only natural aggregates were used with no recycled aggregates. The water cement ratio was kept the same as 0.7. The details of three groups of mixes have been given in Table 5.

Table 5 Mix proportioning of various concrete samples used in the experiment

SNO	Mix Title	Aggregates (New : Recyc : Brick)	Nominal ratio by weight (cement : sand : agg)	No. of samples
1	NRB-1	1:1:1	1:2:4	9
2	NRB-2	1:1:0.5	1:2:4	9
3	NRB-3	1:2:0.5	1:2:4	9
4	NR-1	1:1:0	1:2:4	9
5	NR-2	2:1:0	1:2:4	9
6	NR-3	1:2:0	1:2:4	9
7	N-1	1:0:0	1:2:4	9

3. Results and discussions

First, the fresh concrete mixes were tested for slump and then the concrete cylinders made from various mixes were tested after 7, 14, and 28 days of curing. The test results are presented in Table 6.

3.1 Water cement ratio and slump

3.1.1 Concrete made with new, recycled concrete and brick aggregates.

The water cement ratio has been increased with the addition of recycled aggregates. The W/C ratio is highest for the recycled brick aggregates used in equal ratio to the new and recycled concrete aggregates. The concrete couldn't give any slump for the 0.70 water cement ratio adopted for other mixes and hence it was increased to 0.80. This can be attributed to the porous nature of the recycled bricks aggregates, as the porosity of the brick bats has been observed as more than the recycled and new aggregates. Hence more water content is required to mobilize the aggregates. The demand for more water due to porosity has led to low workability of the concrete and subsequent low strength as well.

When the brick aggregates are reduced and the new and recycled concrete aggregates are kept at the same level (NRB-2), the water demand of the mix has been reduced with substantial increase in the workability. However with the increase of recycled concrete aggregates with the same level of new and brick aggregates (NRB-3), there as increase in the water cement ratio due to porous nature of the recycled concrete aggregates.

3.1.2 Concrete made with new and recycled concrete aggregates

When new and recycled concrete aggregates are used in equal proportion (NR-01) for constant water cement ratio of 0.70, the slump of concrete has been increased with the increase in the proportion of new aggregates (NR-02) almost by 50%. With further increase of recycled concrete aggregates (NR-3), the slump has been further reduced. This is obviously due to increase of the recycled concrete aggregates, which is relatively more porous and require additional water to mobilize.

3.1.3 Concrete made with new natural aggregates

The control mix (N-01) with no recycled aggregates has more slump for the same w/c ratio as the porosity of the aggregates is relatively less. This has also led to increase in the strength of concrete.

Table 6 Test results of various mixes of recycled concrete aggregates

SNO	Mix Title	Aggregates (New : Recyc : Brick)	w/c ratio	Slump (mm)	Compressive strength (MPa)		
					7 days	14 days	28 days
1	NRB-1	1:1:1	0.80	26	6.10 (63%)	8.24 (53%)	10.34 (51%)
2	NRB-2	1:1:0.5	0.70	65	6.50 (67%)	10.31 (66%)	15.36 (76%)
3	NRB-3	1:2:0.5	0.70	37	7.31 (75%)	10.31 (55%)	10.77 (53%)
4	NR-1	1:1:0	0.70	51	8.90 (91%)	9.35 (60%)	14.81 (73%)
5	NR-2	2:1:0	0.70	68	7.80 (80%)	9.35 (66%)	12.91 (64%)
6	NR-3	1:2:0	0.70	37	9.42 (97%)	13.32 (86%)	17.06 (84%)
7	N-1	1:0:0	0.70	69	9.75	15.57	20.27

(The strength of recycled aggregates concrete is expressed as % of the control mix strength)

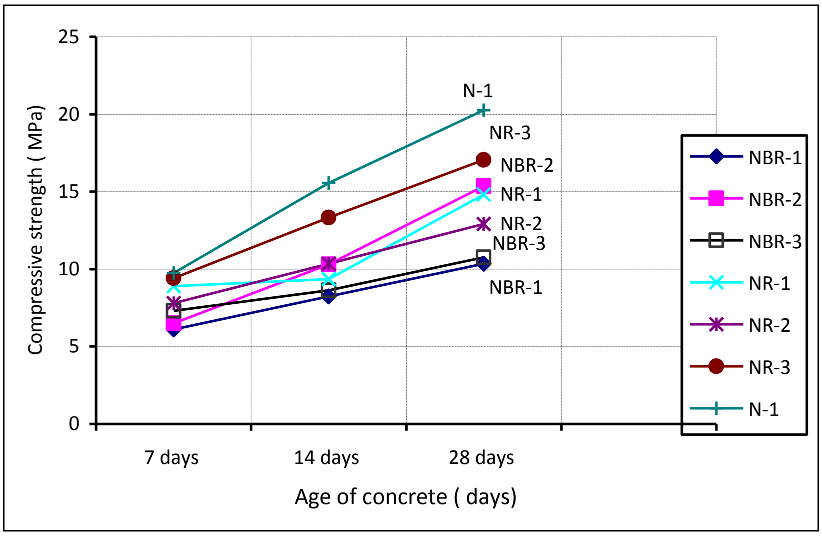

Fig. 2 Compressive strength of various mixes of concrete made of natural and recycled aggregates

From the observations regarding the w/c ratio and workability of the natural aggregates concrete and recycled aggregates concrete, it follows that the slump of recycled aggregates concrete has been increased with the increase of the proportion of the recycled aggregates, particularly for decreased brick aggregates due to its higher porosity. The decrease in the workability of concrete with the increase in the proportion of the recycled aggregates is the natural consequence of added water cement ratio. In brick recycled aggregates, 10% additional water was required for having the nominal slump of 26mm, which is still not a reasonable value for workable concrete and may require additional compaction equipment like vibrators etc in the field. Hence 80-90% water cement ratio may be suitable for such concrete.

3.1 Effect of aggregates on the compressive strength of concrete

The cylindrical compressive strength of the tested specimen at 7 days, 14 days and 28 days were compared with the strength of control mix of N-1 having no recycled aggregates. The highest compressive strength for the recycled aggregates concrete is given by NR-3 after control mix. In

(a) Dry mix of aggregtes of natural, recycled concrete and bricks (NBR-1)

(b) Mixed concrete of of natural, recycled concrete and bricks

(c) Crushed concrete after testing

(d) Closer view of crushed concrete. The failure has taken place by crushing of brick aggregates mainly

Fig. 3 Details of recycled concrete aggregates in mixed and crushed forms

this case the mix of the natural and recycled aggregates is 2:1 with no bricks aggregates used. The 28 days strength has been reduced from 20.27 MPa to 17.06 MPa (15%). The reduction in strength may be compensated in the form of the cost of reuse of the recycled concrete aggregates at one hand and saving of natural resources at the other hand. Similarly the NBR-2 having an aggregate mix of equal proportion of natural and recycled concrete aggregates as 50% of the bricks aggregates have given 14.81 MPa, which is 24% less than the control mix. The mix gives relatively better results incorporating both recycled concrete aggregates and brick aggregates. The results of mix NBR-2 are nearly same as that of NR-1, having new and recycled concrete aggregates in equal proportions. The strength development characteristics of the recycled concrete aggregates are compared with the natural aggregates concrete in Fig. 2.

3.3 Failure pattern of the concrete

The closer observations of the failure of the natural and recycled aggregates concrete has shown various patterns. In recycled brick aggregates blended with recycled aggregates and natural aggregates have shown the cracking of the concrete has been resulted due to crushing of brick aggregates. This is mainly due to low crushing strength of bricks. The crack in the cylinder is also more or less vertical. Hence the crack has mainly developed in one direction as the aggregates interlocking couldn’t play some dominant role and the crushing of brick aggregates led to the

(a)

(b)

(c)

(d)

(e)

(f)

(a, b, c) Cracked sections of recycled aggregates concrete

(d, e, f) Cracking pattern of recycled aggregates concrete

Fig. 4 Details of cracked sections and cracking pattern of recycled aggregates concrete

failure of brick recycled aggregates. The natural and recycled aggregates are mainly uncrushed. The details of NBR-1 are shown in Fig. 3.

The failure of mix of natural and recycled concrete aggregates has exhibited differently. The failure plane has passed mainly through the mortar matrix of the concrete mostly around the old recycled concrete aggregates. Some of the recycled aggregates have also crushed.

4. Conclusions

1. The water requirements of concrete with recycled aggregate is relatively more than natural aggregates concrete due the porous nature of the recycled aggregates. For constant water cement ratio, the slump has been reduced with the increase in the contents of recycled aggregates.

Fig. 5 Details of cracked sections and cracking pattern of natural aggregates concrete

2. The water requirements of the recycled bricks aggregates when blended with the recycled concrete aggregates and natural aggregates, has been increased. The reduction in the bricks contents has led to reduction in the water requirements or increase in the slump.

3. The addition of recycled concrete aggregates have also increased the water requirements or reduced the slump but relatively lesser than the brick aggregates. Hence the porosity of the recycled aggregates plays an important role in the water requirements and slump.

4. The compressive strength for recycled concrete aggregates is relatively more as compared to brick aggregates. Hence the concrete with recycled concrete aggregates can be used in the ordinary plain and reinforced concrete works. However porosity tests and abrasion tests of the recycled concrete aggregates is necessary for determining the suitability of the recycled concrete aggregates in ordinary and structural concretes.

Recommendations for further research

1. The effect of pre-wetting of recycled aggregates to reduce the water requirements and subsequent impact on the compressive strength can be researched further as continuation to this work.

2. Due to porous nature of recycled aggregates, very high water cement content was required, which has reduced the compressive strength of concrete. High Range Water Reducers (Superplasticisers) may be used to reduce the water content and achieve high workability and strength of concrete mixes.

Acknowledgments

The authors are indebted to the support of the Material Testing Labs of Project Directorate Allama Iqbal Open University Pakistan.

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