Workability and Compressive Strength of Recycled Aggregate Concrete with Different Water-Cement Ratios

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Abstract

Use of demolishing waste in new concrete to develop green concrete has proved the need of the day with respect to the preservation of the environment from negative effects and natural sources of the aggregates. This research work presents laboratory investigations on the effect of different water-cement ratios on the workability and compressive strength of concrete made with 50% replacement of natural coarse aggregates with coarse aggregates from demolishing waste. Basic properties: water absorption, specific gravity, and abrasion resistance of both types of aggregates were assessed. A total of eight mixes were designed with water-cement ratios from 0.45 to 0.75 with an increment of 0.05. One mix with 100% conventional aggregates was designed and considered as a control mix to equate the results. A slump test was done to check the workability of all blends. Followed by casting, curing for 28 days, and testing of specimens for compressive strength were done. Test results show that a higher water-cement ratio increases the workability of the concrete but the compressive strength reduces. Assessment of the obtained results with those of the control mix shows a 70% improvement in slump values and a 6.7% reduction in compressive strength with a water-cement ratio equal to 0.55 in comparison to the control mix made with a water-cement ratio equal to 0.45.

Keywords—Recycled aggregates, green concrete, recycled aggregate concrete, water-cement ratio, workability, compressive strength

1 Introduction

In the voyage of mankind, the construction industry has seen drastic changes in terms of appearance, shape, material, construction methods, etc. In present times concrete has proved itself the most frequently used material for construction due to its versatility, strength, and durability. Concrete is a heterogeneous material composed of cement, sand, and crushed in a normal state. Cement is produced at the industry level, whereas the hill sand and crush are generally obtained from stone quarries. Quarrying the aggregates from stone mountains generally requires mechanical power. Usually, blasting is used as the first step in the process. In both process emissions of CO2 and other harmful gases poses serious problems to the environment and need to be addressed properly. Although every country has a set of rules and regulations to control environmental pollution, their implementation is questionable in many places.

Looking at the second face of the development reveals that with time and an increase in population requirement for infrastructure around the globe particularly in city centers has increased. Where on the other hand unavailability of space for new construction adds to the problem. Therefore, the industry is forced for vertical expansion rather than horizontal construction. This most of the time requires the demolition of old, deteriorated, and short-height buildings. The process on the one hand generates a huge quantum of demolishing waste and on the other hand, demands more conventional ingredients of concrete to be produced/quarried. Demand for the ingredients forces the relevant industries to run for more time causing more adverse effects on the environment. Also, the waste generated requires proper management. Usually, the waste is thrown into the landfills. But the unavailability of the space again makes this issue more severe. A possible solution to all these problems is the use of the waste on-site

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particularly in fresh concrete as a replacement of one or other ingredients of conventional concrete partially or in toto. It will lessen the burden on dumping areas (in some cases even the agricultural lands), lessen the running of the quarrying industry, lessen the running time of the cement industry, and lessen the waste management issue. On top of all, it will give the users an option for alternative ingredients for concrete which not only is cheap but available on-site. Therefore, the use of demolishing waste in concrete to produce green concrete is a hot area of research among scholars and researchers.

No matter it is conventional or recycled aggregate concrete, its quality should be ensured to ascertain the durability of the resulting structure. Among several factors pertaining to aggregates, proportioning, workmanship, fresh and hardened properties; workability, and strength of concrete are key parameters. Both factors mainly depend upon the water-cement ratio. Its effect on various properties of conventional concrete both at fresh and hardened states has been well studied. However, since green concrete is used for demolishing waste that is old and has mortar attached to it, therefore, effect of water cement ratio on green concrete must be studied to have a clear insight into its effects on the fresh and hardened properties.

With this aim the research presented in this article proposes the evaluation of the consequence of different water-cement ratios on the workability and compressive strength of concrete made by partially replacing natural aggregates (coarse) with aggregates (coarse) from demolishing concrete waste.

2 Brief account of literature

Demolishing waste being a serious problem around the globe has got the attention of the concerned personnel for years. Its use in fresh concrete is an active research area. Much considerable work has been devoted to the matter. Evaluation of the work summarizes the efforts devoted to the topic in one place for reference to be used by future researchers. To this end, Memon[1] among many others addressed recent developments in 2016 on the usage of demolishing waste as aggregates (coarse) in fresh concrete. The discussion highlighted the problem concerning about recycling of the aggregates, old mortar attached to the aggregates, properties of aggregates, properties of concrete, and the results obtained by different scholars. The article also emphasizes the rules and policies regarding the use of material to make its utilization effective.

Concrete demolishing waste has been attempted by different researchers in fresh concrete. Zheng et al.[2] in their research program replaced conventional coarse aggregates from 0% to 100% with an increment of 25%. The test specimens showed the authors 4.9% and 9.2% reduction in compressive strength for C30 and C50 concrete cast with 100% recycled aggregate. Based on the results they argued that better performance of the concrete can be ensured by using optimal gradation of recycled aggregates. The performance of recycled aggregate concrete in an aggressive environment to check its durability was addressed by Berredjem et. al.[3] The research program made use of demolishing waste both as fine and coarse aggregates to develop C25/30 concrete. Water absorption, capillary, permeability to water and helium gas, and nitrate leaching test of the developed concrete revealed that the old concrete did not show any improvement in durability. The use of recycled sand increased the porosity of concrete thus authors declared the aggregates vulnerable to aggressive environments. Similar findings were recorded by Ali et al.[4] for fresh and hardened properties of concrete made with recycled aggregates.

Several attempts to improve the durability of recycled aggregate concrete are reported in the literature by making use of additives, admixtures and different techniques i.e. use of molasses[4], rice husk ash[5], well water[6], large particle natural aggregates[7], curing types[8][9] are few among a long list. But still, the reduced strength and fluctuating behavior of the material require more work in the field.

Water-cement defines the water required for a workable and consistent mix thus ensuring the required or design strength of the mix. The effect of it on conventional concrete is well understood. However, its effect on various properties of recycled aggregate concrete needs more work to set the standards. To this end Oad et al.[10] studied the effect of the water-cement ratio on recycled reinforced concrete beams. The authors used 0.54, 0.60, 0.65, and 0.70 water-cement ratios to cast the beams. From the comparison of the results with those of conventional RC beams cast with 0.54 w/c ratio, authors observed a maximum of 31.75% reduction in flexural strength. Whereas the deflection and strain in the beams remained within the limits. A lower water-cement ratio showed better flexural strength. The reduction in the strength increased with an increase in the water-cement ratio. Also, the reduced strength resulted in the shear failure of the beams. Choong et al.[11] also attempted to find the relationship and consistency between recycled aggregates from different origins and the water-cement ratio but based on the results of the experimental program they concluded that the addition of RCA increases the water demand for concrete and there does not exist any relationship or consistency between the two parameters. Ali and Roszilah[12] also studied the workability and compressive strength of concrete with recycled aggregates from demolished piles and crushed cubes. Two dosages of recycled aggregates i.e., 30% and 50% were used. From the test results authors observed that 30% dosage is optimum for concrete of grade C40. Whereas 50% dosage was concluded suitable for C15 and C25 concretes. Rao and Sen[13] on the other hand attempted to study and effect of quarry dust (by-product of granite crushing) and water-cement ratio from 0.5 to 0.65 in increments of 0.05 on workability and strength of concrete. From the investigation of fresh and hardened properties of concrete, the writers detected that strength results were reduced with enhancing the water-to-cement ratio. Also, the water demand for concrete increases due to the addition of quarry dust. Optimization of the water-cement ratio to ensure the strength and durability of concrete has also been addressed. In this regard in a research program Naji et al.[14] attempted the same for concrete containing plastic waste. The authors used 2.5% plastic waste and water-cement ratios from 0.3 to 0.5. From the laboratory investigations, they found that a compressive strength gain of 20.2% is possible with the above dose of plastic waste and 0.45 water-cement ratio. Also, it was noted that if the water-cement ratio is reduced to 0.3 strength gain of 36.2The discussion presented above shows clearly that despite of good number of research activities with recycled aggregates or indigenous materials and optimization of water-cement ratio is available in literature the scatter of results and particularly the effect of water-cement ratio on workability and compressive strength of recycled aggregates using demolishing waste is either absent or rare.

3 3. Materials and testing

Recycled aggregates were processed from the demolishing waste (Figure 1) of a slab of a reinforced concrete building by hammering to a maximum of 25 mm size (Figure 2). After sorting for unwanted objects and cracked particles, the aggregates were washed and dried. Washing and drying of conventional coarse aggregates was also done in a standard manner. Additional constituents of concrete i.e. hill sand, cement, and water were selected following the standard requirement of the materials.

3.1 Sieve Analysis

To ensure well-graded aggregates used in the concrete mixes, sieve analysis was performed adhering to the ASTM requirements of both conventional and recycled aggregates. The percentage passing on various sieves is recorded in Table 1. It may be observed that the percentage passing of the aggregates on each sieve is within the prescribed limits. Thus, ensures well-graded aggregates in the proposed concrete.

Fig. 1: Demolishing waste

Fig. 2: Recycled aggregates

3.2 Basic properties

Recycled aggregates being old normally deviate in properties than conventional aggregates. Therefore, in this research program water absorption, specific gravity, and abrasion resistance of the aggregates were de-

TABLE 1: Sieve analysis of recycled and conventional coarse aggregates

#	Sieve	Passiing (%)	
		NAC	RAC
1	1”	91.59	93.00
2	3/4”	23.18	31.55
3	1/2”	2.36	11.73
4	3/8”	0.55	2.18
5	#4	0.00	0.00

TABLE 2: Basic properties of recycled and conventional coarse aggregates

#	Material	Specific gravity	Water absorption (%)	Abrasion (%)
1	NA	2.61	1.14	17.8
2	RA	2.26	4.78	30.8

termined following the procedure specified by ASTM. For the comparison of the results, same properties of conventional aggregates used in this work were also evaluated. The average values of 5 samples of both sets of results are listed in Table 2.

3.3 Slump test

Recycled aggregates in the dosage of 50% were used in this research work. The dose was selected following the recommendation of Oad and Memon [15]. Seven mixes of concrete were planned with a 1:2:4- mix ratio. In each mix different water-cement ratio was used. Additionally, one mix with all conventional aggregates was used for comparing the results. The details of the mixes along with the amounts of the ingredients are specified in Table 3. Each concrete mix was used to check the workability by slump test (Figure 3). The test was conducted in accordance with the procedure specified by ASTM. The obtained results are tabulated in the last column of Table 3.

3.4 Casting and testing of specimens

Following by slump test, five concrete cubes of standard size (6”x6”x6”) were prepared from each batch of concrete in a standard fashion. Weight batching and steel molds were used for the preparation of cubes. Compaction of the specimens was done by table vibrator. After 24 hours specimens were demolded and fully immersed in potable water to cure for 28 days. Once intervene of the curing time, samples were taken out of the water and allowed to air dry (Figure 4). Before testing the specimens for compressive strength, the weight of the specimens was evaluated to check the effect of recycled aggregates on them. All the specimens in turn were then tested for failure load in a universal testing-machine (UTM) under gradually increased load. Figure 5 shows the testing of selected specimens. The weight of the specimens and computed compressive strength are listed in Table 4 and Table 5.

4 Discussion

4.1 Basic properties

The basic properties presented in the previous section are shown graphically in Figure 6 for comparison. The specific gravity of recycled aggregates was observed less (13.4%) compared to the conventional aggregates. The value obtained is better compared to the specific gravity results obtained by Yehia et. al. [16]. On the other hand, the water- absorption of the recycled aggregates was observed greater (41.9%) than that of natural aggregates. The obtained result was 13% less and 15% higher than water absorption reported by Joseph et. al. [17] and Peng et al. [18].
Los Angeles abrasion test results of recycled aggregates show a 73% increase in the value compared to that of conventional aggregates. Further comparison of it shows that the obtained result is 20% and 12% better than the results obtained by Yehia et al. [16] and Joseph et al. [17] respectively. The deviation in all three parameters of the study is indeed due to the old mortar attached to recycled aggregates. The old mortar absorbs more water thus resulting in higher water absorption of the recycled aggregates which need to be adjusted in deciding the water binder ratio of the mix so that the required workability is achieved. The reduction in the specific gravity and increase in abrasion is also due to the same old mortar attached to the aggregates.

4.2 Slump test

Slump test results given in the previous section are compared in Figure 7. An increasing trend in slump value may be observed with an increase in water cement ratio. This confirms the behavior of the recycled aggregates with conventional aggregates. With the same water-cement ratio, the slump value of recycled aggregate-concrete was observed same as that of the control mix. It increased marginally up to batch 4 (w/c ratio=0.6) then more than doubled in the next two batches and last batch (w/c ratio=0.75) it was observed more than 100 mm. Although the result is in good agreement with the slump values reported by Pavan et al. [19] collapse of the concrete cone was observed in the last three batches. This shows that the use of water water-cement ratio beyond 0.6 in recycled aggregate concrete is made with care. Based on the comparison of the results of the parameter it is recorded that the water-cement ratio up to 0.6 improves the workability of the recycled aggregate-concrete. It is also important that the strength evaluation should also be considered before any final conclusion.

TABLE 3: Details of concrete mixes and slump

Mix/Batch	W/C Ratio	RCA & NCA	Cement (Kg)	Fine (Kg)	NCA (Kg)	RCA (Kg)	Water (Kg)	Slump (mm)
Control Mix	0.45	100% NCA	6.4	12.8	25.6	0	2.90	4.0
Batch – 1	0.45	50% NCA	6.4	12.8	12.8	12.8	2.90	4.0
Batch – 2	0.50	+ 50% RCA	6.4	12.8	12.8	12.8	3.50	6.0
Batch – 3	0.55		6.4	12.8	12.8	12.8	3.60	7.0
Batch – 4	0.60		6.4	12.8	12.8	12.8	3.90	8.0
Batch – 5	0.65		6.4	12.8	12.8	12.8	4.20	22.0
Batch – 6	0.70		6.4	12.8	12.8	12.8	4.50	26.0
Batch – 7	0.75		6.4	12.8	12.8	12.8	4.90	102.0

Fig. 3: Synchronous reluctance motor view of stator and rotor

TABLE 4: Weight of concrete cubes

#	Weight (kg) of Specimen							
	Control Mix	Batch – 1	Batch – 2	Batch - 3	Batch - 4	Batch - 5	Batch - 6	Batch - 7
1	8.72	8.83	8.77	8.46	8.51	8.64	8.31	8.27
2	8.75	8.67	8.67	8.66	8.49	8.62	8.29	8.58
3	8.77	8.71	8.43	8.69	8.53	8.56	8.47	8.47
4	8.75	8.68	8.57	8.55	8.58	8.61	8.39	8.36
5	8.74	8.73	8.59	8.78	8.53	8.55	8.59	8.43

TABLE 5: Compressive-strength of concrete cubes

#	Control Mix	Compressive -Strength (MPa) of Specimen						
		Batch – 1	Batch-2	Batch-3	Batch - 4	Batch - 5	Batch - 6	Batch - 7
1	39.75	39.85	35.18	37.07	30.99	34.86	32.58	23.56
2	46.24	43.02	38.99	39.82	31.42	35.79	27.56	24.90
3	47.12	48.00	40.36	44.40	34.43	35.46	33.10	29.33
4	39.90	41.97	38.12	43.15	34.20	33.94	34.96	26.54
5	45.53	38.34	41.07	39.39	24.20	37.64	33.18	26.64

Fig. 4: Concrete specimens

Fig. 5: Testing of specimens

4.3 Compressive strength

The compressive strength results of batch 1 cubes with control mix cubes are shown in Figure 8. Similarly, Figure 9 to Figure 14 shows the comparison of compressive strength of batch 2 to batch 7 specimens with control mix specimens. It may be observed from these figures that due to the induction of recycled aggregates compressive strength of all the specimens remained less than the compressive strength of conventional

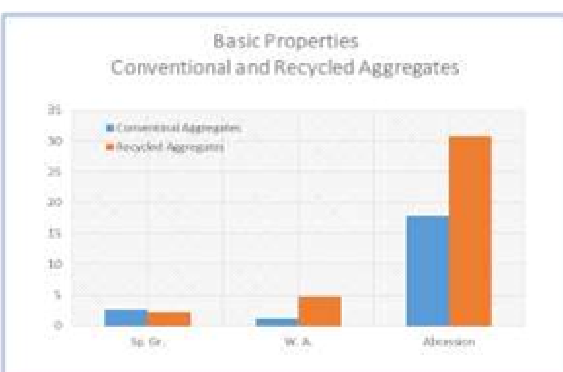

Fig. 6: Comparison of basic properties

Fig. 7: Slump values for all batches

concrete. Two specimens of the batch – 1 showed higher results than the control concrete specimens but considering all other samples it may be attributed to workmanship error i.e., more vibration. The introduction of recycled aggregates affects the compressive strength; it gets aggravated when the water-cement ratio is increased. Mainly the old mortar attached to the recycled aggregates is not strong to the extent of the coarse aggregates Also it absorbs water in case of a higher water-cement ratio resulting in a lesser bond of the concrete matrix.

Figure 16 shows the percentage reduction in compressive strength due to different water-cement ratios. It may be observed that the reduction goes up to 40% in the case of water cement ratio equal to 0.75. With the same water-cement ratio as of control mix the recycled aggregate concrete showed about a 3% reduction in the compressive strength. Whereas, a water-cement ratio equal to 0.55 showed about a 7% reduction in compressive strength and better workability. Therefore, it may be concluded that a 0.55 water-cement ratio is suitable for normal concrete as it not only adjusts the water demand of recycled aggregates but also the reduction is compressive strength is marginal.

It may further be noted from Table 4 presented in the previous section that the effect of an increase in water-cement ratio on the weight of the specimen is marginal. The percentage change in the weight of the recycled aggregate concrete did not deviate even up to 5%. Therefore, it may be concluded that an increase in the water-cement ratio in recycled aggregate concrete does not affect the weight of the specimens.

5 Conclusion

From the experimental investigations on the effect of different water-cement ratios on workability and compressive strength of concrete made with partial-replacement of natural aggregates (coarse) with the

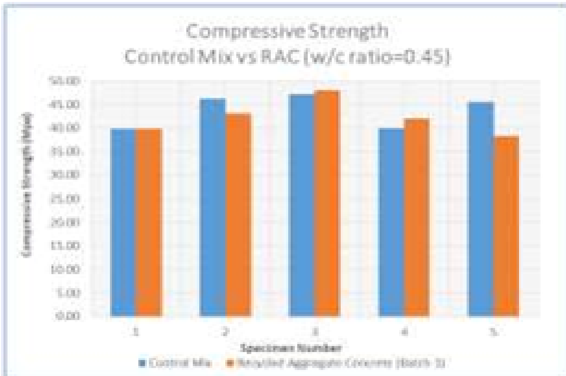

Fig. 8: Compressive strength (Batch – 1)

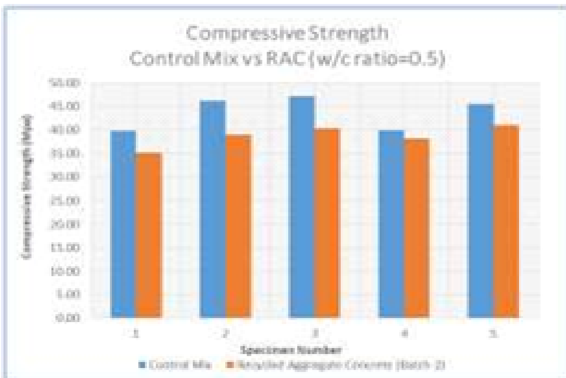

Fig. 9: Compressive strength (Batch – 2)

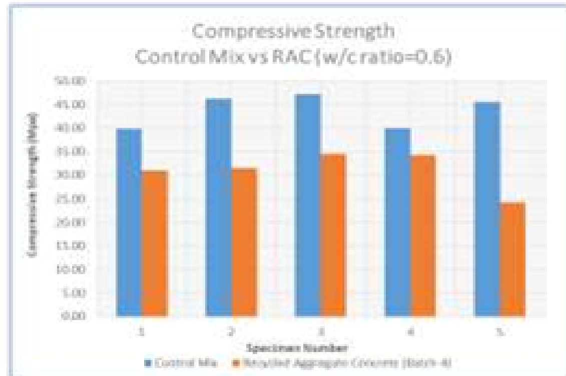

Fig. 11: Compressive strength (Batch – 4)

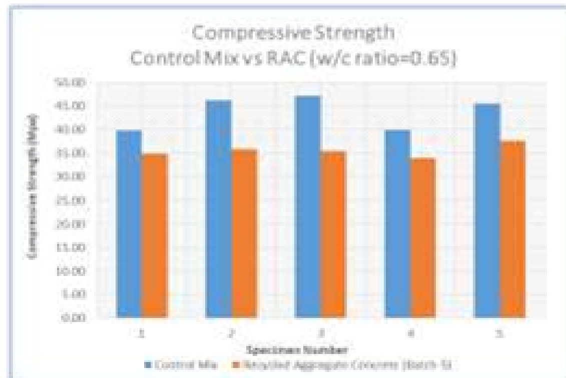

Fig. 12: Compressive strength (Batch – 5)

same from demolished waste of concrete structures following are concluded.

1) Due to old mortar attached to the aggregates abrasion resistance and water absorption is higher. Whereas, the specific gravity of the aggregates is lower.
2) An Increase in water cement ratio improves the workability of recycled aggregate concrete but beyond the water-cement ratio equal to 0.6, collapse of the concrete is observed.
3) Changes in water-cement ratio do not affect the weight of the cubical specimens.
4) Increase in water cement reduces the compressive strength of the concrete. The reduction is recorded in the range of 3% to 40%.

Based on the outcome of this research work it is concluded that water cement ratio equal to 0.55 not only adjusts the water demand of the recycled aggregates but also the reduction in compressive strength is

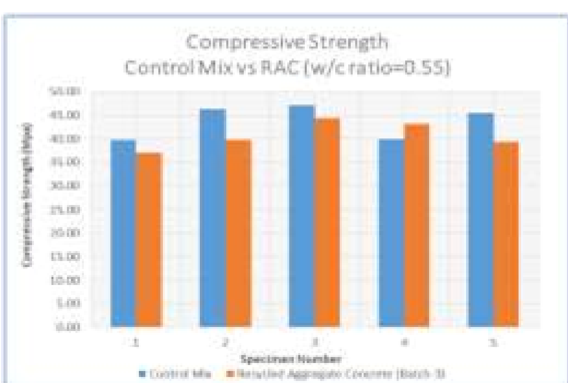

Fig. 10: Compressive strength (Batch – 3)

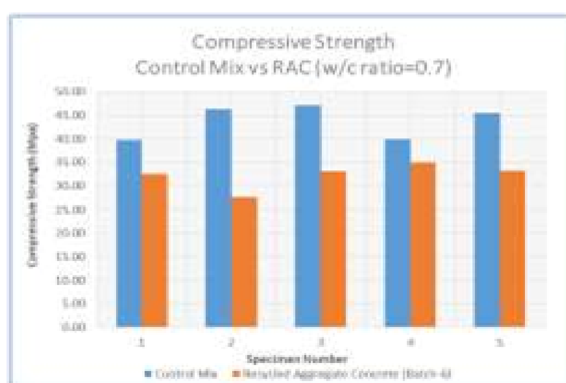

Fig. 13: Compressive strength (Batch – 6)

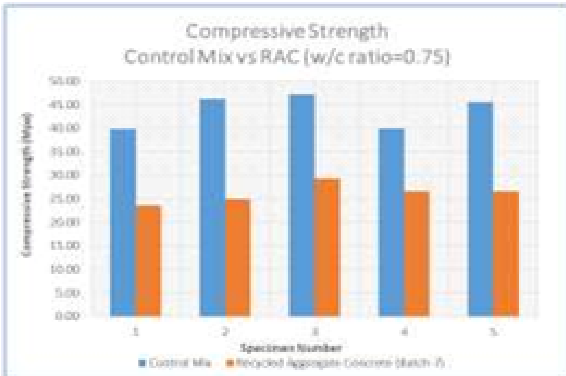

Fig. 14: Compressive strength (Batch – 7)

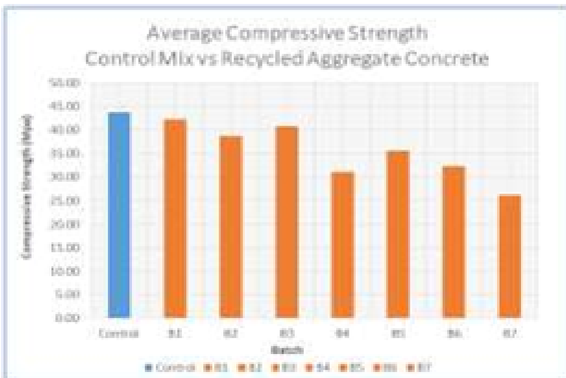

Fig. 15: Average Compressive strength

very marginal.

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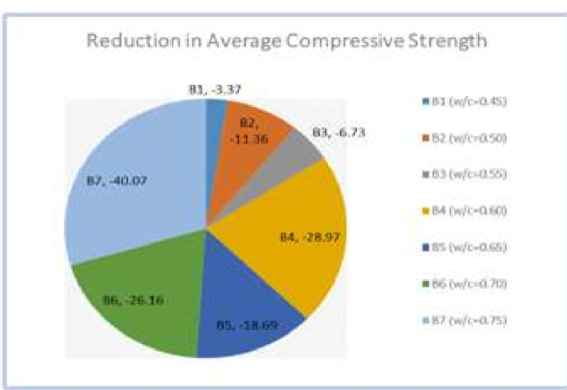

Fig. 16: Reduction in average Compressive strength

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