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Characteristics of Recycled Aggregate Concrete With Respect To Composition and Binder Ratio Variation

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Abstract (10pt)

The current project work is focused on investigating the effect of replacement of recycled concrete aggregate (coarse and fine) over natural aggregate, on the mechanical properties of designed concrete. Three types of concrete were designed for this purpose. The normal concrete (NC) comprises of cement, coarse and fine aggregate, whereas the recycled fine concrete (RF) and recycled coarse concrete (RC) were replaced with 50% recycled fine and 50% recycled coarse aggregate respectively. Furthermore, the three concrete mixes were prepared with varying water to cement (W/C) ratio, i.e., 0.3 (30%), 0.5 (50%), and 0.7 (70%), to study their effect on properties. The experimental investigation concludes that the NC concrete at 0.7 W/C ratio has the highest workability of 480mm^2, and is due to the void spaces caused by the larger sizes of coarse aggregates. The maximum compressive peak load (627.8KN) was obtained for NC at 0.3 W/C content, and that of the minimum value of 214.3KN was obtained for RC concrete at 0.3 and 0.5 W/C content. In some cases viz. NC at 0.3 W/C ratio, RF at 0.3 & 0.5 W/C ratio and RC at 0.7 W/C ratio observed to have a direct relationship between compressive load and density, whereas that of NC at 0.7 W/C ratio had an inverse relation. The RC concrete showed the lowest density compared to NC & RF concrete mixes at each W/C ratio levels.

Keywords:

RAC;
W/C binder ratio;
Aggregate;
Compressive Strength;
Air Content.

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1. Introduction

Cement, water, aggregates (coarse and fine) and admixtures (chemical and mineral) are the core ingredients of concrete production. Concrete has been in use for centuries to build architectural buildings, highways, dams and reservoirs, platforms for various applications, and so forth. Considering the adaptability and suitability towards the environmental change, the goal of concrete production should be protecting the environment, conservation of resources, economization and actual utilization of energy [1]. To accomplish this, the focus has been shifted towards the use of wastes and by-products of cement and construction industries. The recycled aggregate has proved its reliability in this regard with promising results when used in replacement of conventional aggregates for new constructions. Recycled Aggregate Concrete (RAC) hass enough water absorption capacity that leads to increasing water to cement (w/c) ratio resulting decreased density, compressive strength and elastic modulus of the concrete mix [2]. In another work [3] it was observed that flexural strength of the concrete mix decreased marginally with a higher level of replacement of recycled concrete aggregate. The reduced flexural strength was attributed to the reduction in bond strength at the interface between Interfacial Transition Zones (ITZ) and residual and new mortar, as well as the increased residual mortar content resulted from a decline in particle interlocking. Recycled aggregate concrete possesses two interfacial transition zones (ITZ). One is between the RCA and new mortar matrix, and the other is between the original aggregate of RCA and the old mortar attached [4]. RCA has a proportional amount of mortar attached to it that possesses higher porosity and cracks resulting lower strength compared to normal aggregate caused by the formation of a weak link in RAC. Also, shrinkage is one of the concerned issues for RCA as it requires more amount of water compared to normal aggregate. In contrast to the inferior characteristics reported, equivalent and better properties were achieved by using RCA depending on the class of aggregate and mix proportion and liquid- binder ratio [5– 7]. Concretes made with the angular RCA results better flexural strength as that of with round shaped aggregates under reduced water–cement ratio [8]. Lotfy and Al-Fayez [9], performed investigation taking different amounts of RCA (coarse and fine). In their work, it was mentioned that compared to granular recycled aggregate concrete, the coarse recycled aggregate concrete mixes showed better flexural strength, split tensile strength, water absorptivity, chloride permeability and linear drying shrinkage, and those are significantly affected by the ultrafine present in granular recycled aggregates. For a similar nature of work, the reduction in density and water absorption values of recycled coarse aggregate concrete was attributed to the porosity of old mortar adhered to the RCA [10-13]. Also, it was reported that with increasing replacement rate the compressive strength decreased in a linear manner and was concluded that the higher water absorption resulted in the reduced strength. With increase in replacement of RCA the porosity of concrete increases, which can be credited to the paste volume and increse of porosity in recycled aggregates, resulting decreased density. Zaetang et.al [14] studied the influence of RCA replaement over natural aggregate on the properties of pervious concrete. They have reported that the strength of pervious concrete was increased and density was decreased with incorporation of RCA, which was unexpected. The increased compressive strength was credited to the bonding between rough and porous surface of RCA and cement cement paste.

The current research is focused on investigating the compressive strength of concrete mix prepared with the replacement of normal aggregate by coarse and fine recycled aggregates at the different water to cement (w/c) ratio.

2. Research Method

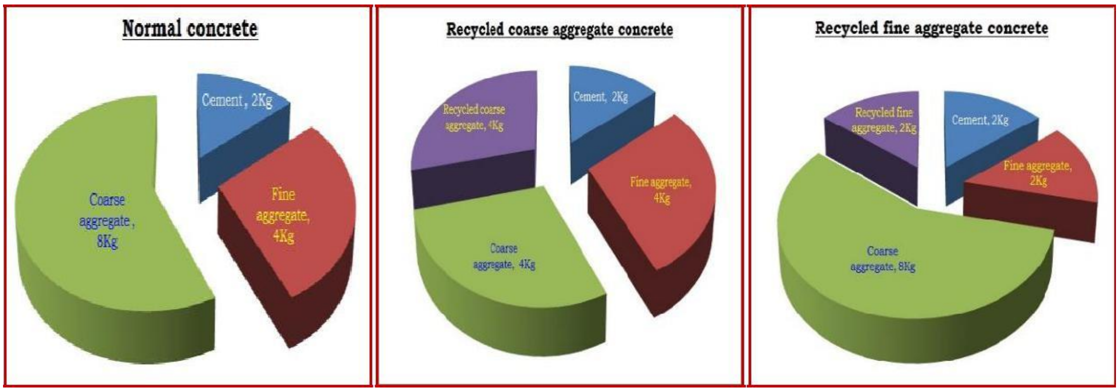
In this current work three different types of concrete mix was designed viz. normal concrete (NC), recycled fine aggregate concrete (RF), and recycled coarse aggregate concrete (RC). The concrete mixes for each category were made by taking three different values of water to cement (W/C) ratio such as 30% (0.3), 50% (0.5), and 70% (0.7). Table 1 below shows the constituent proportions of the three types of concrete mix design. To obtain a clear view on therole of W/C ratio and influence of mixture ratio density and slump tests were also performed on the concrete mixes.

Table 1: Proportion of constituents taken for the preparation of respective concrete mix for the compressive *test.*

Constituents	Normal concrete	50% Recycled fine concrete	50% Recycled coarse concrete
Cement (in Kg)	1.8	1.8	1.8
Fine aggregate (in Kg)	3.8	1.9	3.8
Coarse aggregate (in Kg)	7.8	7.8	3.9
Recycled fine aggregate (in Kg)	0	1.9	0
Recycled coarse aggregate (in Kg)	0	0	3.9
Total aggregate (in Kg)	13.4		

The current study is centered towards investigating the effect of recycled aggregate concrete (RAC) on the strength properties of concrete mix to be used for building construction. To accomplish the primary objective and reach the goal of the project concrete cubes were fabricated in three different ways: (1)

Normal concrete (without incorporating recycled aggregate), (2) concrete with substituting 50% fine recycled aggregate, and (3) concrete with 50% coarse recycled aggregate. The composition of test blocks for slump test is shown in Figure 1. After the slump test had been finished, the air content of respective concrete mix was measured by conducting the air content test following standard procedure. The corresponding concrete mix was prepared following standard procedure. Before pouring the precast into the mold; the mold release liquid was used on the walls of a mold for easy removal of the test block and after solidification air was used to take out the precast from the mold. After pouring the precast into the mold, the whole set has undergone vibration to fill any void spaces present in the precast. The density and compressive strength of respective concrete mix were measured after 28days of water curing.



(a) (b) (c)

Figure 1: Concrete mix proportion for slump test; (a) Normal concrete mix, (b) Recycled coarse aggregate concrete mix, (c) Recycled fine aggregate concrete mix.

3. Results and Analysis

3.1. Analysis of weight difference for different size of aggregates

Figure 2 (a) and 2 (b) illustrates the distribution of various sizes of fine and coarse aggregates respectively, present in 1kg weight of fine aggregate and 2Kg of coarse aggregate. The normal and recycled coarse aggregate didn't have any difference in weight of aggregates belong to any particular size range. Both the recycled and regular aggregates weigh the same amount for all the available range of aggregate sizes. On the other hand, a significant difference in weight wasobserved for the ranges 300 - 425µm, 425 - 600 µm, 600µm - 1.18mm, 1.18 - 2mm, 2 - 3.35mm, and 3.35 - 5mm, aggregate sizes belong to standard and recycled fine aggregates. The difference of aggregate weight was one of the reasons for workability behavior of the prepared concretes and also has a noticeable effect on density as well as compressive load, as the difference in weight can contribute to the voids or porosity of the test block.

Figure 1.*JangerGotra I Mecaling*dance

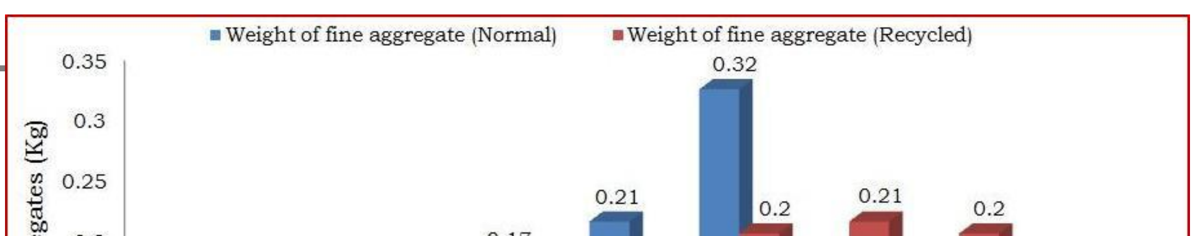


Figure 2: (a) Proportion of different size of Fine Aggregates obtained after sieving.

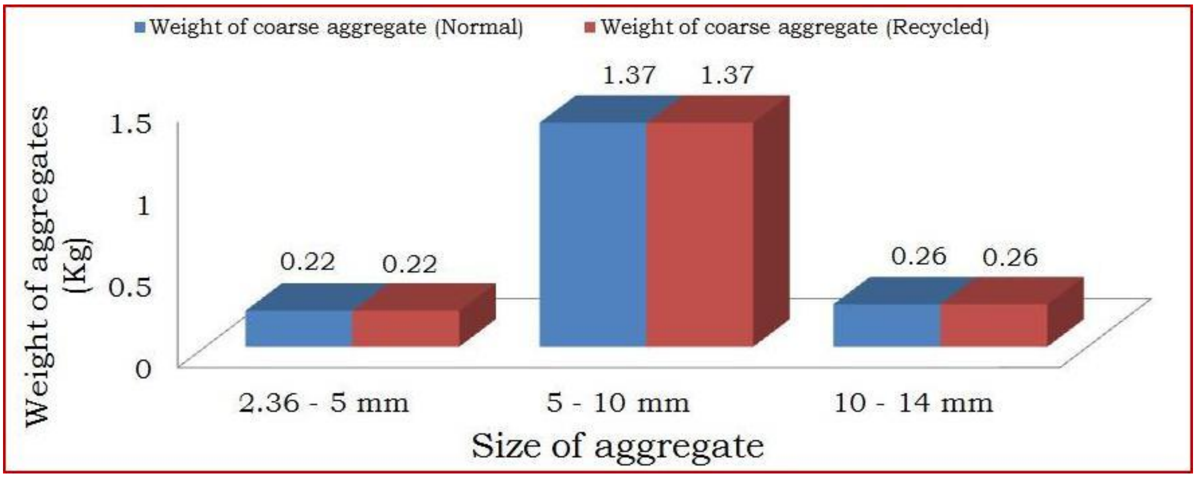


Figure 2: (b) Proportion of different size of Coarse Aggregate obtained after sieving.

3.2. <u>Workability of normal, recycled fine, and recycled coarse aggregate concrete</u>

The slump test results were shown in Figure 3. All of the concrete mixes observed to behave in similar fashion, i.e., with an increase in W/C ratio the slump height is increased. The increase in slump height at higher W/C ratio was attributed to the fact that, coarse aggregate contributes 75% to the total weight of concrete mix leading to more void formation and water absorption, resulting weaker bonding. Also, the recycled concrete aggregate has higher water absorption capacity as compared to natural aggregate, which results in lower workability. Figure 4 provides the evidence of the behavior of concrete mixes under slump test at different W/C ratio. At 30% W/C ratio the mix get dried and hence the slump height is zero and was a true type slump

(Figure 4 (a)). Whereas with the increase in W/C ratio the mix gets wet and resulting increased slump height and was a shear type slump (Figure 4 (b)).

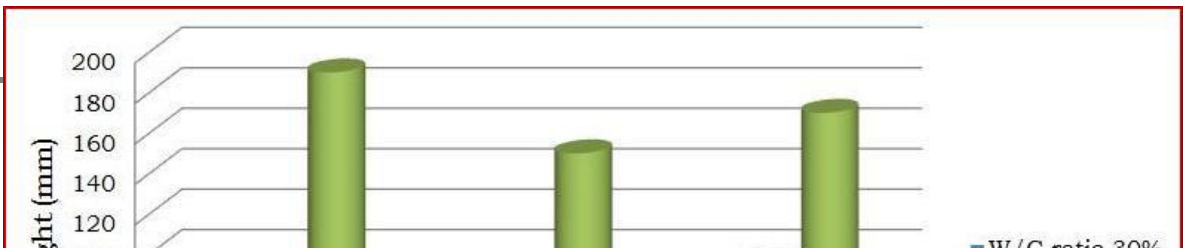


Figure 3: Slump height of normal, recycled fine and recycled coarse aggregate concrete w.r.t. increasing W/C ratio.

(a) True slump (30% W/C ratio) (b) Shear slump (70% W/C ratio)

Figure 4: Slump behavior with increasing W/C ratio.

Table 2: Air content in respective concrete mixes.

W/C ratio	50%
Normal Concrete	One bar =H1 4.1% -----open pressure 0.15% One bar=H2 4.2% ------open pressure 0.15%

RC Fine	One bar =H1 below 8% ----- open pressure 1.6% One bar=H2 below 8% ------ open pressure 2.8%
RC Coarse	One bar =H1 8% ----- open pressure 1.6% One bar=H2 below 8% ------ open pressure 2.3%

3.3. Effect of w/c ratio on density and compressive load

Figure 5 depicts the effect of W/C ratio on density and compressive load of natural aggregate concrete (NC), recycled fine aggregate concrete (RF) and recycled coarse aggregate concrete (RC). The average value of three tests had illustrated for density as well as compressive load. The lowest density value was obtained for recycled coarse aggregate concrete at 30% W/C ratio, and that of highest was found at 50% W/C ratio for recycled fine aggregate concrete. The recycled coarse aggregate concrete had the lowest density at every W/C ratio level, among all the three concrete mixes. The reason is quite evident that the lower amount of fine aggregate (25%) was not able to fill the voids completely in the concrete mix, and the recycled aggregate has higher water absorption capacity compared to the natural aggregate. For water to cement ratio of 30% and 50% the density follows RC<NC<RF, trend. However, the density of recycled fine aggregate concrete is less than that of normal aggregate concrete. The density of NC and RF increased when W/C ratio was increased from 30% to 50% but decreased on further increase in W/C ratio to 70%. Whereas the density of RC increased with increase in W/C ratio because of the water absorption capacity of recycled aggregate leading to the denser packing of fine aggregate into the voids on tapping.

The peak compressive load at different W/C ratio for recycled fine aggregate concrete and recycled coarse aggregate concrete were observed to be opposite in nature. For RF, the compressive load was increased when W/C ratio is increased 30% to 50% and decreased at 70% W/C ratio. Whereas in the case of RC, the compressive load was reduced at 50% W/C ratio and again increased at 70%. The normal aggregate concrete showed a declining trend of the compressive load with an increase in W/C ratio. The maximum compressive load was found for RF and that of the minimum for NC at 50% and 70% W/C ratio respectively. Further, it can be observed that the NC & RC concrete mixes didn't have any correlation between density and compressive strength, whereas compressive strength for the RF concrete increased with increasing density (at 50% W/C ratio) and again decreased at 70% W/C ratio.

The density and compressive load of NC, RF, RC at 0.3, 0.5 & 0.7 W/C ratio, for every test block tested were presented in Table 3. The natural and recycled fine aggregate concrete at 30% W/C ratio observed to have increasing compressive strength with increasing density, whereas for the recycled coarse aggregate concrete noticeable discrepancy was found. The variation in density of Cube1, Cube2 and Cube3 even though keeping all the processing parameters constant, is hard to explain, and the only reason possible could be the presence of voids due to the larger size of aggregates and dry condition of concrete as observed from the slump test. At 50% water to cement ratio, the RF concrete exhibited similar tendency as that at 30%. On the other hand, the strength of RC concrete was declining with increasing density. For the NC concrete, there was no difference in peak compressive load was noticed for Cube1 and Cube3 with density values of 3.56Kg/m^3 and 4.00Kg/m^3 respectively. Whereas Cube2 is having a density of 3.57Kg/m^3, the compressive load was found to be highest among the other two. On further increase of W/C ratio to 70%, the NC concrete perceived to have a decrement in compressive load with increased density level, whereas that for RC the compressive load was observed to have a directly proportional relation with density. On the other hand, the RF concrete doesn't show any particular pattern or correlation between density and compressive strength. However, the overall conclusion was drawn to the point that, normal aggregate concrete at 30% W/C ratio had the maximum compressive strength for Cube1, and that of lowest among all was RC concrete at 30% and 50% W/C ratio for cube2. The fractured test blocks after compressive test are shown in Figure

6. It can be clearly observed that all the designed concretes were failed in normal mode. The load-displacement curves for Cube1, Cube2 and Cube3 of NC, RF, and RC concretes with different water to cement ratio was shown in Figure 7.

Figure 5: Effect of W/C ratio on density and compressive load.

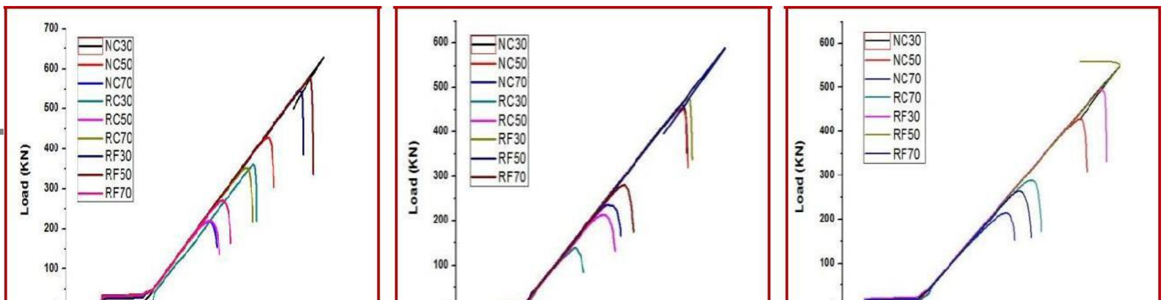
Table 3: Density and peak compressive load for the respective concrete mix.

Aggregate	W/C	Density (kg/m^3)	Peak load(KN)	Failure
Normal Concrete (NC)	30%	Cube1=2.45 Cube2=2.35 Cube3=2.36	Cube1=627.8 Cube2=462.8 Cube3=548	Normal failure
	50%	Cube1=3.56 Cube2=3.57 Cube3=4.00	Cube1=429.1 Cube2=453.8 Cube3=429.2	Normal failure
	70%	Cube1=3.39 Cube2=3.19 Cube3=3.4	Cube1=220.1 Cube2=236.9 Cube3=215.4	Normal failure
Recycle Fine Aggregate (RF)	30%	Cube1=4.00 Cube2=3.38 Cube3=3.39	Cube1=542.8 Cube2=477 Cube3=494.3	Normal failure
	50%	Cube1=3.90 Cube2=3.90 Cube3=3.80	Cube1=577 Cube2=588.8 Cube3=566.5	Normal failure
	70%	Cube1=2.96 Cube2=3.32 Cube3=2.98	Cube1=270.6 Cube2=280.4 Cube3=464.3	Normal failure
Recycle Coarse Aggregate (RC)	30%	Cube1=1.60 Cube2=0.87 Cube3=2.50	Cube1=360.4 Cube2=214.3 Cube3=291.4	Normal failure
	50%	Cube1=2.71 Cube2=2.60 Cube3=2.48	Cube1=220.3 Cube2=214.3 Cube3=228.5	Normal failure
	70%	Cube1=2.90 Cube2=2.89 Cube3=2.70	Cube1=352 Cube2=294.1 Cube3=288.2	Normal failure

7.

(a) (b)

Figure 6: Fractured test cubes of respective concrete mixes; (a) Test cubes of NC, RC, RF concrete, (b) Test cubes of all 27 specimens



(a) Cube1 (b) Cube2 (c) Cube3

Figure 7: Load - displacement curves for Cube1, Cube2 and Cube3 of NC, RF, and RC concretes.

4. Conclusion

The present research was centred towards investigation of compressive strength of concrete by replacement of normal aggregate with recycled aggregate. Three different concrete mix was designed by taking 50% of coarse and fine aggregate along with three different w/c ratio i.e., 0.3, 0.5, and 0.7. The experimental investigation concludes that the NC concrete at 0.7 W/C ratio has the highest workability of 480mm^2, and is due to the void spaces caused by the larger sizes of coarse aggregates. The maximum compressive peak load (627.8KN) was obtained for NC at 0.3 W/C content, and that of the minimum value of 214.3KN was obtained for RC concrete at 0.3 and 0.5 W/C content. In some cases viz. NC at 0.3 W/C ratio, RF at 0.3 & 0.5 W/C ratio and RC at 0.7 W/C ratio observed to have a direct relationship between compressive load and density, whereas that of NC at 0.7 W/C ratio had an inverse relation. The RC concrete showed the lowest density compared to NC & RF concrete mixes at each W/C ratio levels.

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