Quality of Recycled Aggregates and Compressive Strength of No-Fines Recycled-Aggregate Concrete

Shakeel Ahmed Dahri
Department of Civil Engineering
Quaid-e-Awam University of Engineering, Science & Technology, Nawabshah, Pakistan
engr.shakeelahmed9@gmail.com

Bashir Ahmed Memon
Department of Civil Engineering
Quaid-e-Awam University of Engineering, Science & Technology, Nawabshah, Pakistan
bashir_m@hotmail.com

Mahboob Oad
Department of Civil Engineering
Quaid-e-Awam University of Engineering, Science & Technology, Nawabshah, Pakistan
engrmahboob04@gmail.com

Riaz Bhanbhro
Department of Civil Engineering
Quaid-e-Awam University of Engineering, Science & Technology, Nawabshah, Pakistan
riaz@quest.edu.pk

Ihsan Ali Rahu
Department of Civil Engineering
Quaid-e-Awam University of Engineering, Science & Technology
Nawabshah, Pakistan
Ihsanali0999@gmail.com

Abstract- This research paper presents the laboratory investigations of the compressive strength of no-fines concrete made with demolished waste as coarse aggregates used in percentages from 20% to 100%. The basic properties of aggregates were determined. Sieve analysis of both conventional and recycled aggregates was conducted to ensure the existence of well-graded aggregates in concrete. Nine concrete mixes were designed with an aggregate-cement ratio of 4. Additionally, three batches were prepared (conventional, recycled, conventional no-fines concrete) and the results were compared. For all mixes, the water-cement ratio was equal to 0.5. In each batch, 5 cylinders of standard size (total 60 samples) were prepared and cured for 28 days. The weight of the specimens was determined and compressive strength was checked in a Universal Testing Machine under gradually increasing load. A decrease in weight and compressive strength was recorded for the batches of the proposed concrete. Results show that at 40% replacement level the loss of compressive strength is 19% and the weight reduction of the samples was equal to 9%.

Keywords-recycled aggregate concrete; no-fines concrete; compressive strength; demolishing waste; recycled coarse aggregates

I. INTRODUCTION

The demand to reduce the utilization of natural resources and energy and the generation of harmful gases, applies to almost all areas of life. It is reported that every year the concrete industry alone uses 20 billion tons of aggregates, 1.5 billion tons of cement and 800 million tons of water [1]. It also produces 5% - 7% of total global annual CO_2 emissions [1]. On the other hand, the generation of construction waste has increased drastically, making waste management a major issue.

Construction/demolishing waste is usually utilized in floors and plinth protection, but it generally goes to landfills. Unavailability of such spaces forces the industry to transport waste too far leading to increase the cost of the project, while dumbing it in nearby unsuitable areas may cause environmental issues. The conventional ingredients of concrete are believed to be no eco-friendly materials due to the processes involved in their production [2]. Therefore, Recycled Aggregate Concrete (RAC) is one of the solutions in dealing with waste on site and helping to minimize the associated issues to some extent. The use of demolishing waste in new concrete has been addressed by several scholars. Authors in [3, 4] reviewed the recent development on the use of recycled aggregates. Rules and regulations and their implementation regarding the process and use of the material will help to ease the problem. Relevant regulations have been made in many countries, but their implementation has several issues [5]. The use of waste as coarse aggregates up to 100% has been addressed in literature. However, the dialog on total replacement of conventional coarse aggregates is still open. Partial replacement is preferred, particularly to evaluate the optimum recycled waste dosage with respect to strength and durability [6]. The improvement of these and other properties of concrete have also been addressed by making use of different additives, i.e. waste fly ash, waste

Corresponding author: Mahboob Oad

perlite powder, waste cellular concrete [7], silica fume [8], ground granulated blast furnace slag [9], etc.

There are different properties of concrete at fresh and hardened state with varying dosages of recycled aggregates utilized in various ways [8, 10-13]. However, it is observed that the optimum reported dosages by several scholars differ in general and are situation-based in particular. Also, scattering in the results of the same parameters of aggregates or concrete is noticed. This requires more work on the use of recycled aggregates to reach a more unanimous conclusion. Different types of concretes used in the industry have been studied with regard to the use of indigenous materials or waste products. No-fines concrete is one of them. No-fines concrete, also known as porous, pervious, permeable, and cellular concrete, is a porous concrete obtained when fine aggregates are omitted. The most widespread applications of no-fines concrete include road pavements and surface treatments to permit water drainage. In relation to this application, the knowledge of the durability of no-fines concrete has been limited to the study of freezing and thawing, shrinkage, thermal expansion, capacity to percolate water through the cement paste, and abrasion resistance. In addition, no-fines concrete is lightweight and can be utilized in civil engineering applications to reduce the self-weight of the members. Its application in building structures is limited due to the requirement of reinforcement which disturbs the voids present in the concrete. Also, due to the voids in concrete the bonding strength is assumed to be affected. However, it may be used in non-load bearing members to reduce their self-weight. An overview in [14] summarizes the work devoted to the topic along with developing the correlation between various properties of concrete. While producing no fines concrete, gradation of aggregates, aggregate-cement (a/c) and water-cement (w/c) ratios may be chosen appropriately, particularly when the compressive strength is the major parameter of consideration. However, to a limited extent, unit weight and apparent texture also depend on these factors. The strength of concrete is a key property with respect to durability. Due to its porosity, the strength of no-fines concrete is less than conventional concrete's [15, 16]. Therefore, its use is limited to pathways and parking [16], road pavement with limited traffic [17, 18], and blocks instead of bricks [19, 20]. Several attempts have been conducted to improve the strength of no-fines concrete by using partial replacement (up to 20%) of coarse aggregates with fine aggregates [18, 21, 22], reduced w/c and a/c ratios [23-26], fibers [27-29], admixtures including superplasticizers [26, 30], and un-crushed aggregates [31], recycled coarse aggregates [32], or mixes of un-crushed and recycled aggregates [33]. Despite these efforts, still the strength of no-fines concrete is questionable.

Although much work is devoted to various properties of no-fines concrete, only a few studies address the use of demolishing waste in the development of no-fines concrete. The use of waste in no-fines concrete will help the sustainable improvement and lessen the waste management burden on a project. This study aims to investigate the effect of demolishing waste as coarse aggregates on the compressive strength of no-fines concrete. Demolished waste was used in no-fines concrete in percentages from 20% to 100% with increment of 10% and the produced concrete was studied and evaluated.

II. Materials and Testing

In the current work, the demolished waste of a roof projection of single-story house was used (Figure 1). Recycled Coarse Aggregates (RCA) were produced by hammering the waste down to a maximum size of 25mm. After sorting the impurities the aggregates were washed and allowed to dry (Figure 2). The conventional coarse aggregates were purchased from the local market. The source was approved quarries of Jamshoro hills.

Fig. 1. Demolishing concrete waste.

Fig. 2. Recycled and conventional aggregates.

Ordinary Portland Cement (OPC) under the brand name Pak Land of grade ps-42.5N was purchased from the local market. The source of water used for washing and mixing was the local water supply. The water pH was equal to 6.9.

A. Basic Properties

Basic properties, i.e. water absorption, specific gravity, abrasion, and soundness of both types of coarse aggregates was determined following the standard procedures. The obtained results are listed in Table I.

B. Gradation of Coarse Aggregates

To achieve proper strength of the hardened concrete, good gradation of coarse aggregates is a major aspect. Therefore, the gradation of the aggregates was done following the standard sieve analysis procedure. The passing percentage of the aggregates on each sieve is compared and plotted in Figure 3. It can be observed that both types of aggregates, conventional and recycled, confirm the permissible limits.

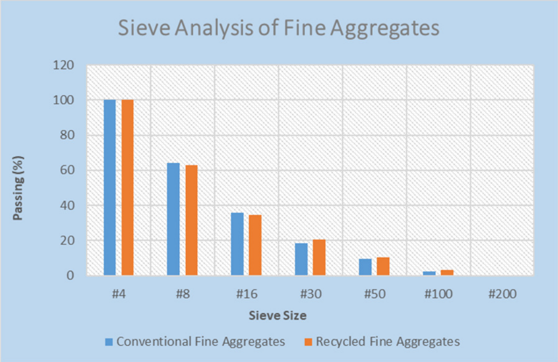

Fig. 3. Sieve analysis of coarse aggregates.

C. Specimen Preparation

To achieve the proposed aim of the research, 8 batches (B4 – B12) of the proposed no-fines concrete were prepared. The Conventional Aggregates (CA) were replaced with RCA in varying percentage from 20% to 100% with increment of 10%. In each batch, 5 standard size cylindrical specimens were cast with 1:4 cement/aggregate ratio. The w/c ratio used was equal to 0.5. A higher value of the parameter was adopted considering the higher water absorption of Recycled Aggregates (RA). Additionally, 3 batches (B1 – B3) were also cast to compare the results of the proposed concrete. The first batch (B1) was cast using conventional concrete (1:2:4 mix). In the second batch, 1:2:4 mix was used, but with all RCA. The third batch (B3) was No-fines conventional concrete with Conventional coarse Aggregates (NCA). The details of all the batches used for this research work along with the quantities of the materials used to cast the specimens in each batch are listed in Table II.

Batching of the ingredients was done using weight batching, followed by mixing the ingredients in a concrete mixer. The moulds were prepared in standard fashion and were filled in 3 layers. Compaction of the specimens of batch B1 and B2 was accomplished using a table vibrator whereas the compaction of no-fines concrete was done by rodding. After 24-hours the specimens were de-moulded and left to air dry for one day (Figure 4). The curing of the specimens was done by fully immersing them in potable water (Figure 5).

Fig. 4. Specimens.

Fig. 5. Curing of specimens.

TABLE I. BASIC PROPERTIES OF COARSE AGGREGATES

Property	CA	RCA	Difference (%)
Water absorption	1.18	4.92	316.95
Specific gravity	2.61	2.31	-11.49
Abrasion	23.7	30.2	27.4
Soundness	4.10	5.86	42.93

TABLE II. DETAILS OF CONCRETE MIXES

Batch	Description	Cement (kg)	FA (kg)	CA (kg)	RCA (kg)	Water (kg)	28 days curing
B1	Conventional concrete	8.807	19.571	36.7	--	3.96	5
B2	RCA	8.807	19.571	--	36.69	3.96	5
B3	NCA	12.33	--	51.4	--	5.54	5
B4	20% RCA and 80% CA	12.5	--	31.7	7.94	5.62	5
B5	30% RCA and 70% CA	12.5	--	27.8	11.9	5.62	5
B6	40% RCA and 60% CA	12.5	--	23.8	15.88	5.62	5
B7	50% RCA and 50% CA	12.5	--	19.9	19.91	5.62	5
B8	60% RCA and 40% CA	12.5	--	15.8	23.83	5.62	5
B9	70% RCA and 30% CA	12.5	--	11.9	27.80	5.62	5
B10	80% RCA and 20% CA	12.5	--	7.9	31.77	5.62	5
B11	90% RCA and 10% CA	12.5	--	3.9	35.74	5.62	5
B12	100% RCA	12.33	--	--	39.71	5.62	5

D. Specimen Testing

After the completion of curing time, the specimens were allowed to dry for 24 hours at room temperature. The weight of all the specimens was determined. The average weight of the specimens in each batch is listed in Table III. Each specimen was tested in a Universal Testing Machine (UTM) under gradually increasing crushing load (Figure 6). The load was recorded and used to compute the compressive strength. The average compressive strength of 5 samples of each batch was evaluated with regard to their weight (Table III).

III. RESULTS AND DISCUSSION

The basic properties of the aggregates presented in Table I show deviations of properties of the RCA from CA. The water absorption is about 3 times the water absorption of the CA. There was a 11% reduction in specific gravity, and 48% and

42% increase in the abrasion and soundness of the aggregates. The results of the parameters of RCA are better than the findings reported in [33-35]. However, the deviation from CA is mainly attributed to the mortar attached with the aggregates, the age and mix ratio of the old concrete, and the conditions to which it is exposed during service life. These factors affect the properties of the aggregates, thus need careful consideration or modified processing techniques to improve the performance of the aggregates.

Fig. 6. Specimen testing.

TABLE III. AVERAGE WEIGHT AND COMPRESSIVE STRENGTH

Batch	RCA (%)	CA (%)	Ratio	Weight (kg)	Compressive strength (MPa)
B1	0	100	1:2:4	13.62	30.86
B2	100	0	1:2:4	12.27	26.41
B3	0	100	1:4	11.61	20.43
B4	20	80	1:4	11.15	18.43
B5	30	70	1:4	10.54	17.40
B6	40	60	1:4	10.62	16.51
B7	50	50	1:4	10.25	15.42
B8	60	40	1:4	10.18	14.23
B9	70	30	1:4	10.11	12.46
B10	80	20	1:4	10.18	11.74
B11	90	10	1:4	10.00	10.35
B12	100	0	1:4	9.90	9.19

The weight of the samples of the proposed concrete are compared in Figures 7 to 9. Figure 7 shows the comparison with the weight of specimens of conventional (1:2:4) concrete. Decrease in the weight of specimens is observed with increase in the replacement level of aggregates. 18% to 27% reduction in the weight of the proposed specimens may be observed in comparison to the conventional (1:2:4) concrete, whereas, the comparison result to Recycled Aggregate (1:2:4) Concrete (RAC) ranged between 9% and 19%. When compared with the weight of conventional no-fines concrete the reduction is in the range of 4% to 15%. This shows that the absence of fine aggregates in the concrete mix results in reduced weight of the product leading to light-weight concrete. However, the strength parameter should also be checked before deciding the optimum percentage of replacement. Otherwise, a higher percentage of RA shows higher reduction in the weight of the product. The percentage difference of the weight of the proposed samples in comparison to B1, B2, and B3 samples is listed in Table IV.

The average compressive strength of the proposed concrete samples is compared with the compressive strength of all three control mixes in Figures 10 to 12. From these Figures it may be noted that the proposed concrete exhibited a reduction in comparison to all the control mixes. Lowest residual strength was recorded at the highest replacement level, and was 30%, 35%, and 45% in comparison to B1, B2, and B3 respectively. This shows that increasing dosage of the RA in no-fines concrete adversely affects the compressive strength of the product. Thus, when producing no fines concrete, the gradation of aggregates and the c/a and w/c ratios may also be chosen appropriately particularly since compressive strength is a major parameter of consideration [37]. The details of the difference of compressive strength are listed in Table V.

TABLE IV. WEIGHT DIFFERENCE PERCENTAGE

Batch	With B1	With B2	With B3
B1	--	9.91	14.77
B2	-9.91	--	5.39
B3	-14.77	-5.39	--
B4	-18.10	-9.09	-3.92
B5	-22.61	-14.10	-9.21
B6	-22.01	-13.43	-8.50
B7	-24.74	-16.47	-11.71
B8	-25.27	-17.05	-12.33
B9	-25.74	-17.57	-12.87
B10	-25.29	-17.07	-12.34
B11	-26.61	-18.54	-13.90
B12	-27.29	-19.30	-14.70

TABLE V. COMPRESSIVE STRENGTH DIFFERENCE PERCENTAGE

Batch	With B1	With B2	With B3
B1	--	16.87	51.03
B2	-14.44	--	29.22
B3	-33.79	-22.61	--
B4	-40.30	-30.22	-9.83
B5	-43.62	-34.11	-14.85
B6	-46.52	-37.50	-19.23
B7	-50.03	-41.60	-24.53
B8	-53.89	-46.11	-30.36
B9	-59.62	-52.81	-39.02
B10	-61.97	-55.55	-42.56
B11	-66.46	-60.80	-49.35
B12	-70.22	-65.19	-55.02

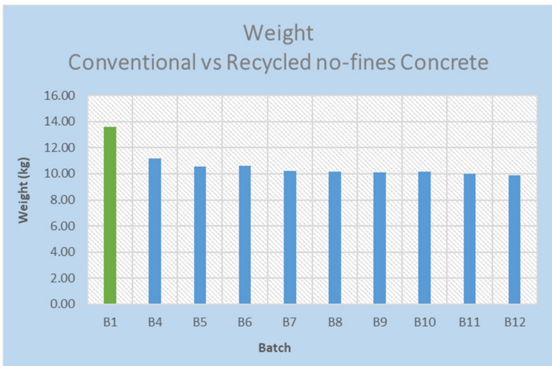

Fig. 7. Weight of B1 vs no-fines RAC.

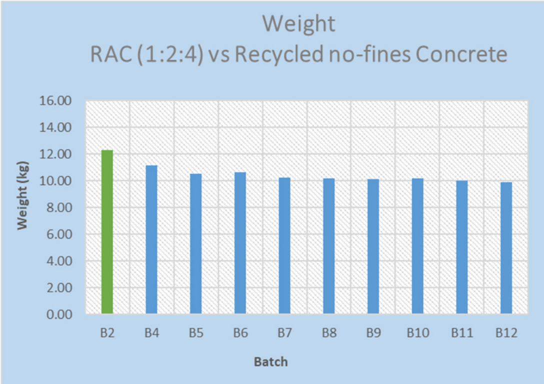

Fig. 8. Weight of B1 vs no-fines RAC.

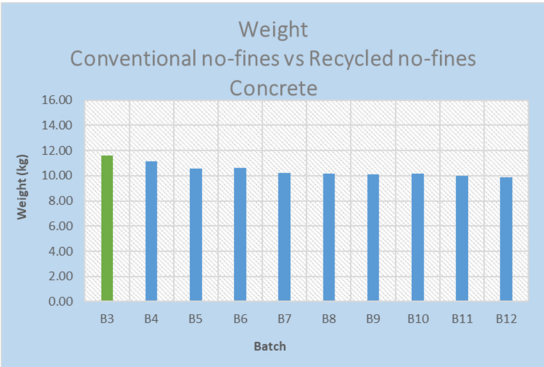

Fig. 9. Weight of B3 vs no-fines RAC.

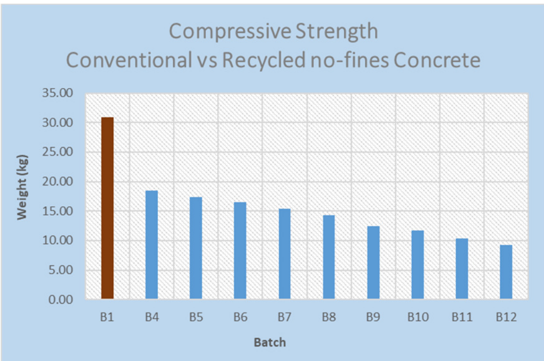

Fig. 10. Compressive strength vs B1.

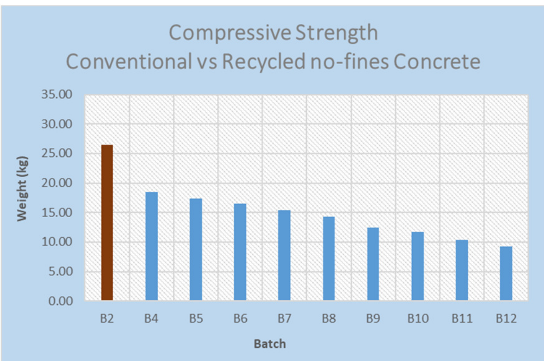

Fig. 11. Compressive strength vs B2

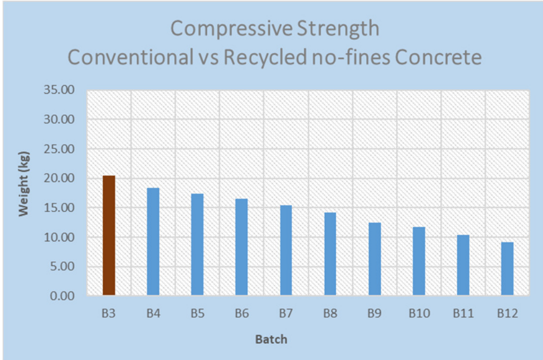

Fig. 12. Compressive strength vs B3.

IV. CONCLUSIONS

From the obtained results of this experimental study, the following conclusions can be drawn:

- Water absorption of recycled aggregates is 316% higher than that of conventional aggregates.
- Specific gravity of recycled aggregates is 11% lower than that of conventional aggregates.
- The abrasion loss of the aggregates is about 27%.
- Soundness of the aggregates is 43% less than the soundness of conventional aggregates.
- The dosage of recycled aggregates is directly proportional to the decrease in weight and compressive strength.
- In comparison to conventional concrete, 27% decrease in weight and 70% loss of compressive strength are recorded at 100% replacement level of conventional coarse aggregates.

Therefore, it may be concluded that recycled coarse aggregates from demolishing waste may be used in the production of the no-fines recycled aggregate concrete. However, considering the loss of weight and compressive strength, 40% replacement level is considered optimum as at this replacement level the decrease in weight and compressive strength is 9% and 19% respectively.

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