Assessment of the Flexural Strength of No-Fines Recycled Aggregate Concrete Prisms

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ABSTRACT

This study investigated experimentally the flexural strength of no-fines recycled aggregate concrete, produced using 20-70% replacement of conventional coarse aggregates with coarse aggregates from demolished waste. Six prisms in each dosage with a 1:4 mix and 0.5 water-binder ratios were prepared. A batch of prisms with conventional aggregates was also cast to compare them with the proposed concrete. An equal number of samples were cured for 7 and 28 days and tested under a gradually increasing central point load to examine failure load, central deflection, and flexural strength. The comparison of results showed an increasing trend in deflection with an increase in the dosage of recycled aggregates. The 7-day cured samples had approximately 2.6 times the deflection of conventional concrete. However, the deflection at all replacement levels remained less than that allowed by ACI-318. The results showed a decreasing trend in flexural strength with an increase in the dosage of recycled aggregates. The 40% replacement sample had a less than 20% strength reduction and is recommended as the optimum level of replacement of conventional aggregates for the production of no-fines recycled aggregate concrete.

Keywords-flexural strength; no-fines recycled aggregate concrete; demolishing waste

I. INTRODUCTION

The construction industry has used a variety of materials to build safe and reliable infrastructures and meet the needs of inhabitants and trends of society. As concrete is currently the most widely used material in the construction industry due to its versatility and durability, the rapid construction development brings a burden on its natural resources. In parallel, changes in infrastructure lead to a drastic increase in demolitions and, consequently, waste generation. In previous decades, landfills were commonly available to accommodate this waste, but nowadays the lack of space around city centers, aesthetics, and environmental policies complicates the management of such waste. Furthermore, this waste cannot be dumped in or around cultivated lands, as it would cause serious impacts on the agricultural sector and the economy of the area in general. Most demolishing waste is used in floors, plinth protection, or similar filling sections but still, the residual waste raises worries. A possible solution could be the reuse of concrete waste material in new concrete to produce an indigenous green product. However, there is a need to investigate better the behavior of waste materials and their effects on the fresh and hardened properties of concrete, although several studies attempted to examine the use of demolishing waste in new concrete [1].

Concrete is used in a variety of forms in modern infrastructures. Low-strength concrete, such as no-fines concrete, is commonly used in non-structural members, such as in partition walls in place of bricks or pavements for better drainage. However, it may also be used for other types of structures in non-structural members or low-load areas. This study investigated the use of demolition waste as coarse aggregates to produce no-fines recycled aggregate concrete and examined its flexural strength.

II. LITERATURE REVIEW

The use of recycled aggregates is an globally active research field. A summary of the most recent developments was presented in [1], discussing processes, issues, and effects on the hardened product, and proposing a few recommendations for its smooth and confident use in the industry. In [2], demolition waste was used as low-grade coarse aggregates, while authors in [3] concluded that better concrete properties can be achieved if the source of the recycled aggregates is high-strength concrete. In [4], an investigation on the use of high-strength recycled concrete did not show an effect of the replacement percentage on the slump flow of the resulting concrete but about a 10% reduction in compressive, split tensile, and flexural strengths. In [5], a 5% reduction in split tensile strength was observed at equal replacement of conventional coarse with recycled aggregates. In [6], the properties of concrete from demolished waste were investigated in fresh and hardened states, along with its long-term effects. It is obvious that there is a wide scatter of results of the relevant studies.

In parallel to modifications in the normal concrete matrix for better performance, several studies investigated the development of no-fines concrete. No-fines concrete was initially developed for road pavement in areas of low traffic volumes, as its main features are good drainage of surface water or recharge of the groundwater table. Its initial development and progress were reviewed in [7]. Several studies examined the mechanical properties of no-fines concrete for road pavement, highlighting its efficiency in low-volume traffic areas [8-12]. The compressive strength of no-fines concrete for road pavement was evaluated in [13], finding that although its strength was lower compared to conventional concrete, it was suitable for low-traffic pavements. Normally, single-sized coarse aggregates are used in the development of no-fines concrete. In contrast, graded aggregates were used in [14] to develop no-fines concrete and study its compressive strength, finding that 10-20mm was the most suitable grading as it showed a compressive strength equal to 15.7MPa. Different additives such as silica fume [15], limestone dust [16], fly ash [17-18], ground granulated blast furnace slag [18], etc., have also been used to improve the performance of no-fines concrete. The use of additives improved the performance of the no-fines concrete but it is still not as that of the conventional concrete. Therefore, additional research is required to improve its properties and performance. Improvement in the performance of no-fines concrete has also been attempted using very small quantities of fines in concrete, showing improvement in strength but a reduction in its permeability characteristics, which, in some cases, is the main requirement [19]. Other studies attempted to improve no-fines concrete using uncrushed aggregates [20], fly ash with admixtures [21], different mixtures and water-binder ratios [22], GGBS [23], etc.

Not only compressive strength is important, but also flexural strength. Therefore, a variation of fly ash and plasticizer was used in [24] to study the flexural strength of no-fines concrete, designing 5 different mixes, and concluding that 60% fly ash with 0.5% plasticizer and 0.17 water-binder ratio was optimum for producing equal or more flexural strength than conventional concrete. Furthermore, it was noted that extreme care should be taken in dose decisions, as higher doses of plasticizer can increase slump and reduce flexural strength. In [25], 1:2 and 1:3 mixes were used to develop no-fines concrete and study its compressive, tensile, and flexural strengths, concluding that 12.5mm was the most suitable size for coarse aggregates, the 1:2 mix was better than the 1:3, and observing a 23% reduction in flexural strength in comparison to the conventional. In [26], 30% less flexural strength was observed in no-fines concrete. The development of green concrete was also attempted using plastic waste and nano-silica [27], recycled binder concrete [28], and sugarcane bagasse ash and limestone fines [29]. Green concrete made with RCA was also studied in [30] for strain and displacement under sustained loading of 12 months, showing only a 10.34% deviation from the control concrete.

Despite the scattering in the results, it is evident that many research efforts focus on improving no-fines concrete, but it is also evident that few studies focus on the use of recycled aggregates in the production of no-fines concrete. This study aimed to investigate varying percentages of recycled aggregates in the production of no-fines concrete, study its flexural strength, and provide a good insight into its use.

III. MATERIALS AND METHODS

Demolition waste was collected from slab debris from a two-story building to prepare no-fines concrete. Large pieces of concrete, as shown in Figure 1, were hammered manually to produce coarse aggregates of 25mm maximum size. Conventional coarse aggregates from Nooriabad hills and fine aggregates from Bolhari hills were obtained from the local market. Conventional and demolished coarse aggregates were cleaned and washed, as shown in Figure 2, and sieved to ensure their quality. Figure 3 shows the gradation curve of both aggregate types, and it can be observed that the trend of both curves and the ranges on various sieves fall in the specified ranges of ASTM C-136 [31].

Fig. 1. Demolishing waste.

Fig. 2. Aggregates.

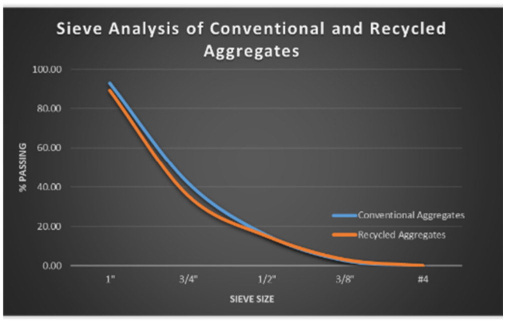

Fig. 3. Sieve analysis of coarse aggregates.

Table I shows the basic properties of both conventional and recycled aggregates.

TABLE I. PROPERTIES OF AGGREGATES

Description	CA	RA
Water absorption	1.14	2.51
Specific gravity	2.61	2.65
Fineness modulus	6.2	6.43
Surface texture	Fairly smooth	Rough
Appearance	Angular	Angular

IV. RESULTS AND DISCUSSION

After curing, the samples were tested on a Universal Testing Machine (UTM) under a central point load following the provisions of ASTM C-293 [32], as shown in Figure 5. The samples were carefully monitored during testing, and the crushing load and central deflection were recorded at failure. The average of the observations in each batch and curing age were calculated. Flexural strength was evaluated using the standard formula:

$$\sigma_f = \frac{3PL}{2bd^2} \quad (1)$$

where the σ_f is flexural strength, P is failure load, L is length, and b_d is the cross-section of the prism. Tables II and III show the average values of load, deflection, and flexural strength for 7- and 28-days cured specimens, respectively.

Fig. 4. Prism specimens.

Fig. 5. Testing of specimens.

TABLE II. AVERAGE LOAD, DEFLECTION, AND FLEXURAL STRENGTH OF 7-DAY CURED SPECIMENS

Concrete	Load (kN)	Deflection (mm)	Flexural Strength (MPa)
Conventional Concrete	3.87	0.7	2.90
Concrete with 20% RCA	3.51	0.9	2.63
Concrete with 30% RCA	3.11	1.1	2.34
Concrete with 40% RCA	2.98	1.3	2.23
Concrete with 50% RCA	2.65	1.5	1.99
Concrete with 60% RCA	2.07	1.6	1.55
Concrete with 70% RCA	1.95	1.8	1.46

TABLE III. AVERAGE LOAD, DEFLECTION, AND FLEXURAL STRENGTH OF 28-DAY CURED SPECIMENS

Concrete	Load (kN)	Deflection (mm)	Flexural Strength (MPa)
Conventional Concrete	4.42	0.6	3.31
Concrete with 20% RCA	4.12	0.7	3.09
Concrete with 30% RCA	3.81	0.9	2.85
Concrete with 40% RCA	3.66	1.1	2.74
Concrete with 50% RCA	3.15	1.2	2.36
Concrete with 60% RCA	2.60	1.4	1.95
Concrete with 70% RCA	2.36	1.5	1.77

Figures 6 and 7 show a comparison of the average flexural strength for the 7- and 28-days cured samples of the proposed with the conventional no-fines concrete. The average flexural strength of the no-fines conventional concrete was recorded at 2.9MPa for 7- and 3.31MPa for 28-day cured samples, 71% and 62% higher than in [21]. The recycled concrete samples achieved 2.63MPa to 1.46MPa from 20% to 70% replacement of conventional coarse aggregates, which were better for up to 40% replacement than in [21]. On the other hand, for 28-day cured samples up to 50% replacement, the results were higher than in [21]. Similarly to the 7-day cured samples, they showed a decreasing trend in flexural strength with increasing recycled aggregates. The maximum strength (3.31MPa) was observed at 20% replacement, while the minimum (1.77MPa) was recorded for the maximum replacement. Table IV shows the percentile difference in flexural strength of no-fines recycled aggregate concrete concerning the conventional. The reduction in strength is mainly attributed to the attached mortar, the age, and the exposure of the old concrete.

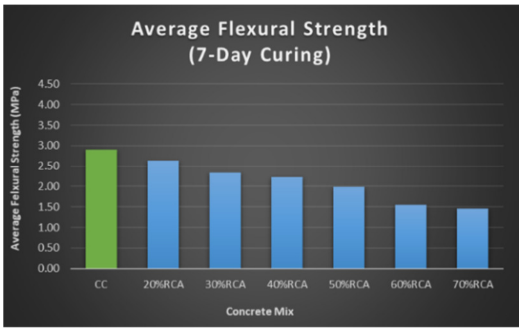

Fig. 6. Average flexural strength (7-day curing).

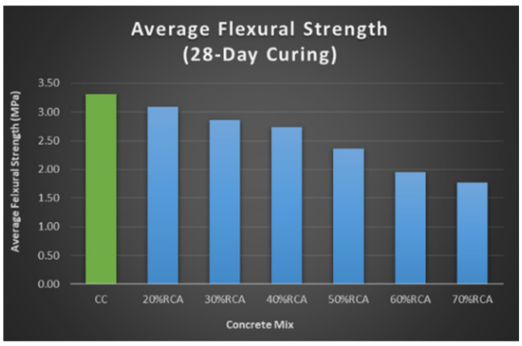

Fig. 7. Average flexural strength (28-day curing).

Figures 8 and 9 show a comparison of the average central point deflection at failure load in all prisms to no-fines conventional concrete. An increasing pattern in deflection with increasing the replacement of coarse aggregates is recorded. The maximum deflection was 1.8mm and 1.5mm for the 7- and 28-day cured specimens, respectively. Table IV also lists the percentile difference in deflection for both curing ages of the proposed concrete specimens. The maximum deflection was about 2.5 times the deflection of the conventional 7-day cured no-fines concrete samples. It is also noted that all deflection values are within the allowable limits of ACI-318 [33] for simply supported beams.

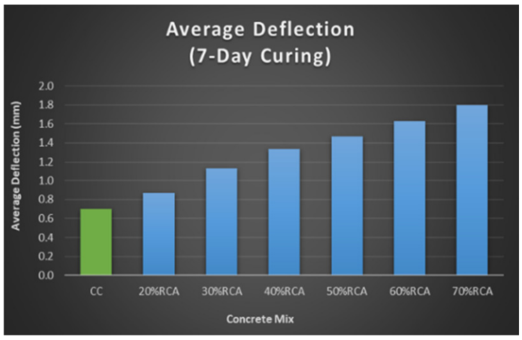

Fig. 8. Average deflection (7-day curing).

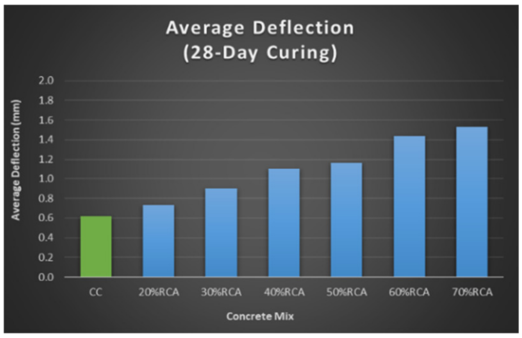

Fig. 9. Average deflection (28-day curing).

TABLE IV. PERCENTILE DIFFERENCE OF FLEXURAL STRENGTH AND DEFLECTION

Concrete Mix	7-Day Curing		28-Day Curing	
	Deflection	FS	Deflection	FS
Conventional Concrete	--	--	--	--
Concrete with 20% RCA	23.81	-9.22	18.92	-6.81
Concrete with 30% RCA	61.90	-19.45	45.95	-13.81
Concrete with 40% RCA	90.48	-22.99	78.38	-17.18
Concrete with 50% RCA	109.52	-31.42	89.19	-28.74
Concrete with 60% RCA	133.33	-46.58	132.43	-41.11
Concrete with 70% RCA	157.14	-49.61	148.65	-46.55

The observed failure mode of the beams was flexural failure, as shown in Figure 10. As plain concrete prisms were used in this study, flexural failure confirmed the concrete failure mode. Hence, it was concluded that recycled aggregates from demolished waste are suitable for producing no-fines concrete. However, considering the flexural strength and its loss (about 7%) compared to conventional no-fines concrete, the 20% replacement was considered as optimal.

Fig. 10. Failure mode.

V. CONCLUSION

Based on the experimental investigation on the flexural strength of no-fines recycled aggregate concrete, the following can be concluded:

- The flexural strength of no-fines recycled aggregate concrete decreases with increasing replacement level of coarse aggregates.
- Central point deflection increases with increasing replacement level of coarse aggregates.
- The 20% replacement specimens, cured for 28 days, had maximum residual strength.
- All recorded deflections for both 7- and 28-day cured samples were less than the allowable deflection for simply supported beams as per ACI-318.
- All prisms failed in flexure mode at the center.

Therefore, it can be concluded that demolished waste may be used as recycled aggregates in no-fines concrete with 20% as the optimum replacement level for conventional aggregates.

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