Assessment of the Flexural Strength of Binary Blended Concrete with Recycled Coarse Aggregates and Fly Ash

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ABSTRACT

This study investigated the effect of blending fly ash and recycled aggregates as replacements for cement and conventional coarse aggregates, respectively. Recycled concrete helps to reduce waste management issues and protect the environment. Fly ash was used in percentages from 0% to 10% with an increment of 2.5%, whereas demolition debris was used in a proportion of 50% with conventional aggregates. The 1:2:4 mix with a 0.5 w/c ratio was used to make six concrete mixtures, one of them made entirely of congenital aggregates. Slump tests were performed for all mixtures. A total of 30 prisms of size 500×100×100mm were made and cured for 7 and 28 days. The flexural strength of the specimens was assessed under a two-point bending test till failure. The 5% fly ash and 50% Recycled Coarse Aggregates (RCA) mixture produced better results than the other mixes, showing a decrease in flexural strength of 10.74% and 15.75% after 7 and 28 days of curing, respectively. The small reduction in flexural strength compared to preserving conventional deposits and reducing the hazardous environmental impact of cement production and debris waste makes this mix suitable for use in structural members.

Keywords-green concrete; recycled aggregates; demolishing waste; fly ash, workability; flexural strength; two-point loading

I. INTRODUCTION

Many researchers are actively investigating partial or alternative replacements for concrete materials to increase the strength of the final concrete and protect the environment from the emissions caused by the primary manufacturing processes of concrete ingredients. Many different materials have been investigated for this reason, among them demolition rubbles from concrete constructions as coarse aggregates in fresh concrete. As garbage management is an important concern, using filler material as coarse aggregates in fresh concrete on the work site has many advantages. Yet, the quality of aggregates and the concrete created in this way are impacted by the age of the concrete and the old mortar adhering to it. In particular, green concrete's strength is lower than that of conventional since it uses recycled aggregates from demolition waste. For a few decades, research has actively sought strategies to address this shortcoming. The effects of green concrete on the environment and its contributions to a sustainable environment were studied in [1-2]. The inconsistent nature of the waste's reported results demonstrates the need for additional research in the field to increase confidence in its application [3-4]. In [5-6], the basic properties of materials, the workability of wet concrete, and the mechanical behavior of concrete incorporating different replacement levels were determined, suggesting the use of Recycled Coarse Aggregates (RCA) at suitable replacement levels. In [7-10] the effects of curing methods, water-cement ratio, and temperature on hardened concrete with recycled aggregates were investigated.

Fly ash is a very fine powder created during the primary combustion process. Every year, large amounts of this waste are produced all over the world, seriously harming the ecosystem. Fly ash has been used in concrete as a pozzolanic cement replacement (siliceous and aluminous) to reduce waste and its associated issues. When water is added, calcium hydroxide interacts with it and creates cementitious compounds. In [11], fly ash was reviewed as a supplementary material for concrete and mortar, focusing on its chemical properties and concluding on its use as a sustainable material for green concrete production. To create M15, M20, and M25 concrete, fly ash substituted cement in amounts of 20%, 40%, and 60% in [12], presenting a numerical model for the strength vs water-cement ratio based on the obtained fundamental and strength characteristics of the concrete. The curves developed from the model can be used to calculate the amount of fly ash needed to provide the required strength on concrete.

In [13], fly ash was used to produce high-strength concrete, showing an increase in strength and a decrease in sorptivity after 28 days of curing. Fly ash was also used to create concrete without increasing carbon dioxide emissions [14], suggesting the use of stainless steel as a reinforcement and cladding for greater longevity. In [15], fly ash was used in large volumes as a cementitious compound to study micromechanics characteristics, showing that its use increased the tensile strain capacity of the concrete, but the compressive strength determines its dosage. In [16], fly ash and alkaline solutions were used to determine the mix design criteria and produce cement-free concrete. The comparison to standard concrete revealed strong connections. In [17], laboratory research was conducted on the use of fly ash from 10% to 30% by volume of cement, showing that although fly ash had a detrimental effect on compressive strength, a dosage of up to 20% resulted in increased density and tensile strength. In [18], fly ash was used in dosages of 0-20% to produce M20-grade concrete, exhibiting increased strength and durability after 7 and 28 days of curing. In [19], quarry dust and fly ash were used in dosages of 0-30%, concluding that using both materials together improved strength and contributed to environmental preservation.

Fly ash has a significant impact on the strength of concrete, but this impact varies greatly depending on the water-to-cement ratio. Early strength is often lower when fly ash is used as a substitute compared to ordinary Portland cement [20]. When using large amounts of fly ash, the final strength may not exceed 70% of the control mixture. Hydration products (CSH jell) are formed when fly ash combines with calcium ions in the pore solution of concrete and water [21-23]. Authors in [24-26] concluded that the replacement of cement with suitable doses of fly ash in conventional or recycled concrete has positive effects that can lead to indigenous material and environmental preservation to some extent.

Many studies have been conducted on fly ash as a cement replacement, but very few investigated the use of both fly ash and demolished concrete as partial or total replacements for cement and coarse aggregates, respectively. It is evident that more studies are required to fully understand the collective effects of materials on the strength properties of concrete. As a consequence, this study examined the impact of using fly ash as a partial replacement for cement on the flexural strength of concrete made with a partial replacement of conventional coarse aggregates with recycled concrete. Furthermore, this study evaluated strength under two-point loading, which is believed to be better than the one-point loading generally used.

II. MATERIALS AND TESTING

This study used ordinary Portland cement from Pakistan and hill sand from a nearby market which was sieved to eliminate lumps and larger particles. The aggregates came from debris from the demolition of a two-story reinforced concrete building in Nawabshah, Pakistan, and the huge blocks were pounded to generate coarse aggregates with a maximum size of 25mm. The aggregates were cleaned, washed, and then left to dry after removing unwanted materials. The same-sized traditional coarse aggregates acquired from the local market were washed and dried. Fly ash class C from a coal power plant was used as cement replacement in weight-for-weight doses of 0, 2.5, 5, 7.5, and 10%. Figure 1 shows the aggregate produced from demolished waste and Figure 2 shows the cement, sand, and fly ash.

A. Sieve Analysis

Hill sand from approved sources from the local market was used as fine aggregates. Figure 3 shows the aggregate sieve analysis. The fineness modulus of the fine aggregates was 2.4. The percentage passing through various sieves and the fineness modulus of the aggregates was within the allowable range of ASTM C136/C136M-14 [28]. Figure 4 shows the sieve analysis results of both the conventional and the recycled aggregates, following the normal practice to verify properly graded aggregates in the concrete mix. The fineness modulus of the aggregates was 5.33 for Normal Concrete Aggregates (NCA) and 5.35 for RCA. The results of the sieve analysis were within the allowable ranges of ASTM C136/C136M-14 [28].

Fig. 1. Coarse aggregates.

Fig. 2. Fine materials.

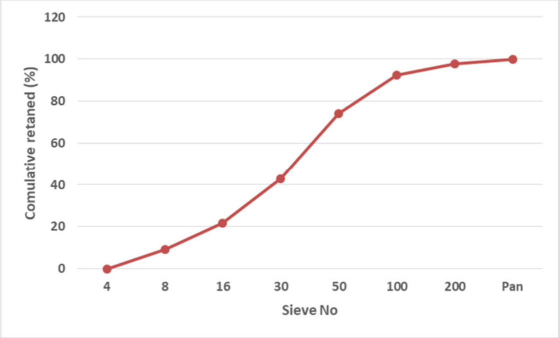

Fig. 3. Sieve analysis of fine aggregates.

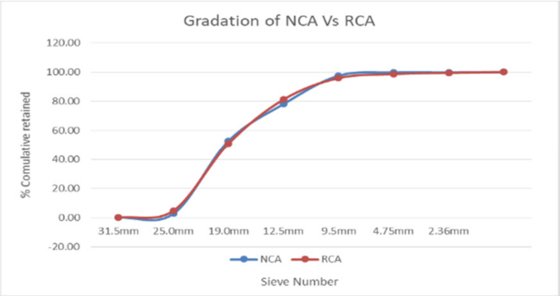

Fig. 4. Sieve analysis of NCA and RCA.

B. *Mechanical Properties of Aggregates*

The mechanical properties of aggregates play an important role in the preparation of the desired concrete, particularly water absorption and specific gravity. Table I shows the determined water absorption, specific gravity, abrasion, soundness, and impact and crushing values of both NCA and RCA, following the relevant ASTM standards [30].

TABLE I. WATER ABSORPTION AND SPECIFIC GRAVITY

Test	NCA	RCA
Water absorption	1.64	3.42
Specific gravity	2.57	2.31
Abrasion	18.5	43.1
Soundness	3.9	5.62
Impact value	19.8	28.4
Crushing value	26.2	34.1

Equal halves of traditional coarse aggregates and debris from demolition building waste were used. The dosage of recycled aggregates was chosen according to [27]. Concrete ingredients were combined in a 1:2:4 ratio with a 0.5 water:cement ratio. Six different concrete mixes were prepared, namely CM, B1, B2, B3, B4, and B5. Fly ash doses of 0%, 2.5%, 5%, 7.5%, and 10%, each with 50% recycled aggregates were used for 5 concrete mixes, while only traditional elements were used to produce the control concrete mix (CM). The water used had a pH level of 6.7 (see Table II).

TABLE II. MATERIAL DETAILS

Batch #	Cement (kg)	Fly Ash (%)	FA (kg)	NCA (kg)	RCA (kg)	Water (kg)
CM	10	0	20	40	0	5
B1	10	0	20	20	20	5
B2	9.75	0.25	20	20	20	5
B3	9.5	0.5	20	20	20	5
B4	9.25	0.75	20	20	20	5
B5	9	1	20	20	20	5

C. *Workability of Concrete*

Each concrete mix was tested separately using the slump cone method to check its workability, according to ASTM C143 [29], and Table III shows the results.

TABLE III. SLUMP CONE RESULTS OF ALL MIXES

Batch No.	Fly Ash (%)	Slump (mm)
1	0.0	50.0
2	0.0	42.0
3	2.5	41.5
4	5.0	41.0
5	7.5	39.5
6	10.0	38.0

D. *Preparing and Curing of Specimens*

Five prisms of 500"×100"×100" were prepared for each of the 6 batches. The concrete was prepared for the molds, poured, and compacted according to the ASTM C31/31M-19 [30]. The specimens were demolded on the next day and allowed to dry in the air for 24 hours in the laboratory. All specimens were then totally immersed in potable water for 7 and 28 days. Thus, a total of 60 specimens were used in this study. Figure 5 shows the specimens and the curing process.

E. *Flexural Strength*

After the respective curing time, the specimens were moved out of the water and their surface was wiped off with a dry clean cloth. The specimens were then dried in the air for 24 hours. A universal testing machine was used to determine flexural strength under two-point loading, following ASTM C78 [31]. The load application rate on the testing device was set to 0.5kN/sec, and it increased until failure. Figure 6 shows some specimens and Table IV shows the specimens' flexural strength, as calculated from their failure load and dimensions using the standard formula.

Fig. 5. Casting and curing of specimens.

TABLE IV. AVERAGE FLEXURAL STRENGTH

#	Batch	Fly ash (%)	7-day curing		28-day curing	
			Mean load (KN)	Mean strength (N/mm^2)	Mean load (KN)	Mean strength (N/mm^2)
1	CM	0.0	7.02	5.29	8.77	6.61
2	B1	0.0	5.82	4.37	7.28	5.46
3	B2	2.5	5.91	4.42	7.39	5.53
4	B3	5.0	6.34	4.72	7.646	5.572
5	B4	7.5	5.76	4.32	6.80	5.10
6	B5	10.0	5.42	4.01	6.41	4.80

Fig. 6. Beam testing.

III. RESULTS AND DISCUSSION

The results of the fine aggregate sieve analysis were used to evaluate the fineness modulus, which was found to be in the range of fine sand. The percentage of the aggregates passing on various sieves met the required ranges. Both used coarse aggregates confirmed the standard requirements of well-graded aggregates. With only a small variation in range values over a sieve, both curves' trends were quite comparable and the percentage passing on various sieves met the requirement of coarse aggregates. The water absorption of recycled aggregates was 108% more than that of conventional, while the specific gravity was 11.25% less. Similarly, the abrasion values, the soundness, and the impact and crushing values were 132%, 44%, 43.4%, and 30% higher. The deviation of the properties of the recycled aggregates confirms the findings of previous studies and shows that the strength of the concrete using the aggregates may also be affected. Indeed, the deviation was due to the age and exposure of concrete during previous use and mortar attached to the recycled aggregates. Thus, the higher demand of the recycled aggregates for water was adjusted in the water-cement ratio, and 0.5 was adopted.

The slump test results indicate that the slump of traditional concrete was within the acceptable range. However, the results of other mixtures were lower than those of ordinary concrete. Figure 7 compares the slump values of the mixes with the control mix. It can be noted that adding more fly ash caused the slump value to decrease more. The maximum slump decrease, which was approximately 30%, was seen for 10% fly ash cement replacement. This shows that there is more water needed for mixes with fly ash. Furthermore, while choosing the w/c ratio for the mix, more admixture or mechanical effort will be needed to maintain the requisite workability.

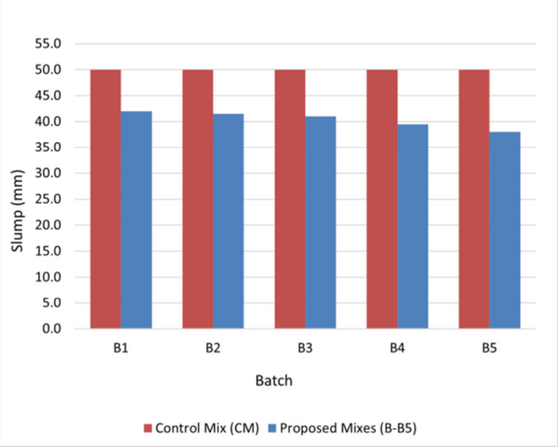

Fig. 7. Comparison of slump values.

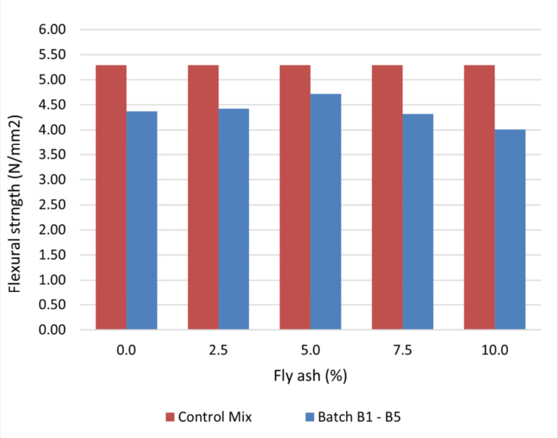

Fig. 8. Flexural strength (7-day curing).

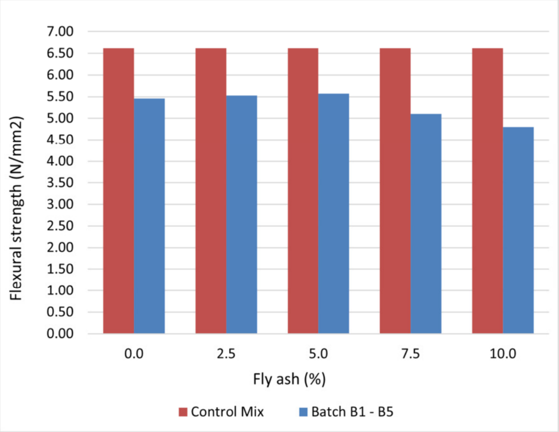

Fig. 9. Flexural strength (28-day curing).

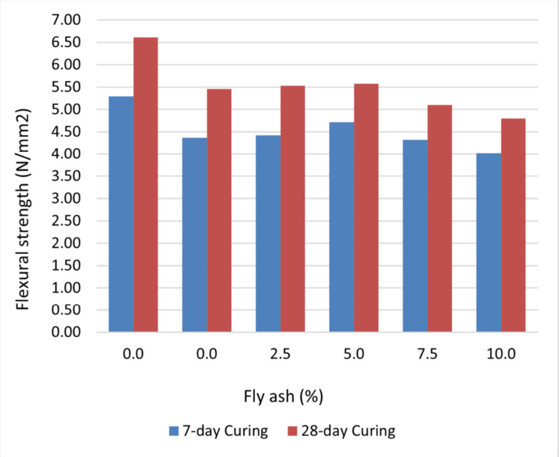

Fig. 10. Average flexural strength comparison of 7- and 28-day cured specimens.

Figures 8 and 9 compare the average flexural strength of all specimens. It was observed that the included RCA affected flexural strength by 17.40% and 17.51% for 7- and 28-day curing, respectively. On the other hand, the addition of fly ash up to 5% countered the problem and gave a better result. The increase of fly ash beyond 5% decreased flexural strength. Increasing fly ash percentage reduced both workability and flexural strength. The results show the comparison of average flexural strength between the control mix and the one using just 50% recycled aggregates. Among all the mixtures, the mix with 5% fly ash and 50% recycled aggregates provided the highest flexural strength. The average flexural strength decreased by 10.74% and 15.75% for 7- and 28-day cured specimens, respectively, when compared to the control mix.

Figure 10 compares the flexural strength results for the 7- and 28-day cured specimens, showing the same trend of increase in strength. For the standard curing period of 28 days, it may be observed that the loss of strength due to the use of recycled aggregates was counteracted by the addition of 2.5% of fly ash. A similar trend in strength was observed with 5% fly ash in addition to the small increase in strength, but further addition of fly ash resulted in a decrease in strength. This was attributed to the lesser bonding capability of fly ash than cement. Based on these results, the recommended dosage of fly ash was 5% along with 50% RCA from demolished waste.

IV. CONCLUSION

This study used fly ash and recycled aggregates from demolition debris in concrete to investigate their impact on the workability and flexural strength of concrete. The mechanical properties of aggregates were found to maintain the workability of the desired concrete, particularly water absorption and specific gravity. The findings showed that the specific gravity of RCA was lower and that their water absorption was higher than that of natural coarse aggregates. The greater water absorption of the recyclable aggregates increases the water requirement of the concrete mix, demanding an adjustment to the design. It was also observed that as the dosage of fly ash increased, the slump value of concrete mixed with all conventional constituents decreased. To maintain workability, an adjustment of the water-to-cement ratio in line with the water absorption of recycled aggregates is necessary, otherwise, greater mechanical effort or admixture will be needed during preparation and compaction. Flexural strength results showed that a dosage of 5% fly ash is ideal since it resulted in the least loss of flexural strength for both cases of 7 and 28 days of curing. Therefore, 50% recycled concrete aggregates from demolished concrete waste with fly ash up to 5% are recommended for concrete with good residual flexural strength compared to conventional concrete.

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