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EFFECT OF CLASS-C FLY ASH ON COMPRESSIVE STRENGTH OF RAC MADE WITH RECYCLED AGGREGATES FROM DIFFERENT STRUCTURAL MEMBERS

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Abstract
In this research study laboratory investigation to check the effect of fly ash in recycled aggregate concrete made with recycled aggregates from different structural members is presented. Conventional aggregates are replaced with recycled aggregates from demolished waste in the dosage of 35%. Demolished waste was used from five structural members. In each group of recycled aggregates, class C-Fly ash was used from 0 to 15% in the increment of 2.5%. In each batch 15 cylinders of standard size were used. For preparation of all specimens 1:2:4 mix with 0.5 water cement ratio was used. Out of 540 cylinders equal number was cured for 7-, 28-, and 90-days. From the compressive strength test results, it was observed that addition of fly ash improves the strength characteristics of recycled aggregate concrete but up to 10%. Among recycled aggregates from different structural members, recycled aggregates from column concrete performs better than others. 28-day cured samples showed better results than 7-, and 90-day cured samples with maximum increase in strength equal to 17.07%. Effect of mixed aggregates on compressive strength revealed better performance of elongated curing.

INTRODUCTION

In present era sustainable development has become the need of the day. It not only helps in protecting the environment but also in reducing the hazards effects to human health. In construction industry same is also the case. Massive infrastructure development everywhere not only require huge quantum of the conventional aggregates but also generates large quantities of construction and demolished waste. Both cases result in negative impacts to environment and depletion of conventional resources of the aggregates. Life cycle of the originally developed concrete in shape of demolished waste continues posing serious problems to various aspects of human life. Hence green concrete utilizing the waste in new concrete will not only ends the life cycle of the waste but also will help in preservation of conventional

aggregates, protection of environment, safety to human health, development of indigenous green material. Therefore, good time and energy has been devoted by research community around the world in developing methods and measures to recycle the waste to be used in new concrete and its effects on various properties of concrete.
Concrete is matrix of cement, fine and coarse aggregates. First and second components are used in lesser quantities than coarse aggregates therefore, more scope of using demolished waste as coarse aggregate is valid as it will consume more waste thus leads to lessen the waste management issue to some extent. Demolished waste has been used as coarse aggregates by many researchers around the world [1], [2]. However, despite of good time and energy devoted for the research on topic still the scatter in the obtained results is a big hurdle in reaching to a level of confidence in using the material. Age of the concrete, exposure of concrete, old mortar attached to the aggregates, pores and various other issues affects the properties of aggregate to greater extent resulting in inferior properties of recycled aggregates than conventional aggregates [3]. These properties in turn affect the fresh and hardened properties of the concrete using the aggregates, particularly the strength properties [4]. On the other hand, strength is the key property and should be ensured for proper safety and serviceability of the concrete.
Lesser strength of recycled aggregate concrete needs to be improved so that it can be used in structural members. To this several things, i. e. plasticizers, admixtures; synthetic and natural materials, fly ash, marble dust, granite particles and powder, rice husk ash, silica fume, minerals, steel, saw dust ash, medical waste, electronic waste, etc. In different conditions different benefits have also been reported in literature. However, still unique solution is absent. This demands more work in the area to be done to reach certain level of confidence in use of the material. Among different additives fly ash is a waste material available abundantly everywhere in the world as it is the byproduct of coal burning. It also needs proper disposal management to protect environment and human health. In turn it has cementous properties, therefore, is used as partial replacement of cement. Its use in concrete give bifold benefit of reduced waste management and alternative material of the cement. Fly ash has also been attempted in conventional and recycled aggregate concrete as cement replacement and admixture to improve its properties. But its use in recycled aggregates concrete with recycled aggregates from different structural members is seldom.
Therefore, this research study proposes the use of recycled aggregates from demolishing of five different structural members in development of recycled aggregate (green concrete) along with varying dosage of class C-fly ash as cement replacement. Compressive strength of the cylindrical specimens cured for 7-, 28-, and 90-days will be determined. The results of binary blended concrete will be analyzed and compared with those published in literature. The outcome will give clear understanding of the effect of recycled aggregates from different structural members and fly ash on compressive strength at standard and elongated curing ages.

Literature review

In this section brief account of available state-of-art literature relevant to the proposed topic of research is given. It summarizes the already published work relevant to the use of proposed waste material, also, highlights the scatter of the results and thus need of the more work in the area.
Abera [5] conducted research to study the effect of demolished waste as fine and coarse aggregates on the fresh and hardened properties of normal and light weight concrete. Separate use of waste as fine and coarse aggregates from 10% to 100% with increment of 10% was made in both type of concretes considered. When used as coarse aggregates compressive strength was record 30% less at 35% replacement level in normal concrete. Similar reduction was observed by the author while using demolished waste as fine aggregates in normal concrete, whereas for light weight author recommends 40% dosage as optimum with least reduction in compressive strength. Effect of recycled aggregates from demolished waste on compressive strength was also studied by Goumathy et. al. [6]. The study used 0, 10%, 20%, and 30% dosage of aggregates along with superplasticizer. Compressive strength results revealed the positive effect of superplasticizer on recycled aggregate concrete with 4% higher values than conventional concrete at 30% replacement level. In contrast to conclusion of

reference [6], Lianes et. al. [7] found 50% replacement of conventional aggregates with recycled aggregates as optimum dosage from compressive strength test. Mahakud et. al. [8] also observed 50% replacement as optimum from the compressive strength results of recycled aggregate concrete made with 100% replacement of conventional aggregates. Lesovik et. al. [9] used different dosages than other, i.e., 33.3%, 66.7%, and 100% with silica fume as admixture to improve the strength properties of the concrete. Compressive strength test results of 28-day cured samples showed improvement in the results with silica fume by 9.95%. Whereas without it the compressive strength result was 6.12% less than conventional concrete. Both results were observed at 100% dosage of recycled aggregates.

Different other techniques have also been used for improvement of the compressive strength. Among them effect of type of curing is one. Ali et. al. [10] used different curing techniques to check their effect on compressive strength of recycled aggregate concrete and found steam curing gives best results than open air, water, gunny bags and sprinkle curing.

Fly ash being mineral admixture has cementous capabilities and has been used in concrete as cement replacement. The same was used by Krishnamoorthi and Kumar up to 30% along with quarry dust. Results revealed potential use of both material for strength improvement. Authors in [12] observed optimum dosage of fly ash equal to 10% with RCA dosage equal to 40% from the compressive strength results of sixteen batches of concrete samples. Bajad et. al. [13] also used fly ash in recycled aggregate concrete to prepare concrete cubes using 1:2:4 mix and 0.5 water cement ratio. Their recording of the results reveals 30% as the optimum dosage of the fly ash. Additionally, the authors also developed numerical expression based on dosage of RCA and fly ash to predict the compressive strength of the concrete. Fly ash has also been used by Sowmith and Babu [14] in recycled aggregate concrete. The dosage of fly ash used was 10% and 20% with four replacement levels of conventional aggregates with recycled aggregates. From the compressive strength test results optimum dosage of fly ash was observed equal to 10% and dosage of RCA was recorded equal to 50%. The authors also argues that the double mixing system gives better results than conventional mixing system.

On contrary to others, authors in [15] observed negative impact of fly ash on compressive strength concrete.

Rohman and Aji [16] while checking effect of fly ash on strength parameters of recycled aggregate concrete observed 10% as optimum form the test results of 28-day cured concrete cylinders cast with varying water cement ratio. Authors also used SPSS to develop the numerical relation for predicting the compressive strength. The developed numerical relation performed well with their used examples. In another study on use of fly ash in conventional concrete Khan and Ali [17] used fly ash up to 15%. Authors compared the test results of stress-strain curve, load-deflection curve and strength properties with conventional concrete and concrete containing coconut fibers. Observation revealed that 10% dosage of the fly ash in concrete yield better results than other two counterparts used in the study. Nithyambigai et al. [18] used varying water cement ratio, recycled aggregates, and fly ash to check the effect on compressive strength. Test results of 7-, 14-, and 28-day cured samples showed 20% dosage of fly ash as optimum. Fly ash has also been used by Chandio et. al. [19] in recycled aggregates concrete to prepare cylinders of standard size. The fly ash was used up to 10%. Recycled aggregates were used from mix debris. Compressive strength test results showed that 5% of the fly ash is optimum with 11% reduction in the strength in comparison to conventional concrete. In another research study on use of pozzolanic material in concrete Raj et. al. [20] used fly ash as cement replacement in 10% and 20%. Three different replacements of recycled aggregates were used to prepare and cure the samples for 7-, and 28-days. 28-day compressive strength of the concrete showed that 10% fly ash and 50% RCA give reasonably good results.

It may be observed from the above discussion that both recycled aggregates from demolished waste and fly ash from coal burning has been used separately and collectively in preparation of concrete. Other than above discussed literature, several other scholars have also conducted research using the materials to study strength and other properties of the concrete. In Table 1 optimum dosage of fly ash reported in few articles among several other is listed. It may be observed that there is no consistency in the reported dosage of the fly ash, but it ranges from 5% to 50%. Also, above discussion shows that recycled aggregates are used from mixed demolished waste. Separate work on waste from different structural members is either absent or seldom. Therefore, this research study aims at evaluating the effect of recycled aggregates from different structural members and fly ash. Additionally, effect of elongated curing on compressive strength of proposed concrete will also be studied.

Table 1: Summary of dosage of fly ash from available literature

#	Reference	Reported optimum dose of fly ash
1	Dabhade et. al. [12]	10%
2	Bajaj et. al. [13]	30%
3	Sowmith et. al. [14]	10%
4	Helepciuc et. al. [15]	20%
5	Rohman and Aji [16]	10%
6	Khan and Ali [17]	10%
7	Nithyambigai et. al. [18]	20%
8	Chandio et. al. [19]	5%
9	Raj et. al. [20]	10%
10	Maguesvari et. al. [21]	30%
11	Teja et. al. [22]	50%
12	Kumar et. al. [23]	20%
13	Divya et. al. [24]	20%

Material and Testing

Conventional ingredients

For the ingredients of concrete matrix, cement used in this study is ordinary Portland cement under brand name Lucky cement. It was sieved using #200 sieve to ensure its fineness. Percentage retained (<20%) confirms its fineness with relevant ASTM standards. Hill sand obtained from approved quarries was used as fine aggregates. It was sieved in standard fashion. Percentage passing on various sieves is listed in Table 2. Coarse aggregates of maximum 25 mm size were also obtained from approved quarries for this research work. The material was thoroughly sorted for unwanted substances followed by washing and drying at room temperature for 24-hours. To ensure properly graded aggregates in concrete mix the material was sieved as per relevant ASTM standards. Percentage passing on various sieves is given in Table 3. The fineness modulus of conventional coarse aggregates was noted equal to 5.13. It may be observed for both fine and coarse aggregates that percentage passing confirms with the ranges specified by relevant ASTM standards. For mixing the ingredients water used was obtained from water supply line. Its pH value was found equal to 6.7. Cement, hill sand and crush are shown in Figure 1.

Table 2: Percentage passing of fine aggregates

Sieve size (mm)	Percentage passing	ASTM range
4.75	100	95 – 100
2.36	91.5	80 – 100
1.18	67	50 – 85
0.6	37.9	25 – 60
0.3	11.5	10 – 30
0.15	5.3	5 – 30
0.125	0	0 – 10

Table 3: Percentage passing of coarse aggregates

Sieve size (mm)	Percentage passing						ASTM range
	Conventional Aggregates	RA-S	RA-B	RA-C	RA-F	RA-L	
25	96.45	96.95	97.4	96.75	96.4	95.9	90 – 100
19	60.2	55.25	53.9	52.25	60.9	51.4	35 – 70
12.5	24.7	21.25	18.65	12.00	26.4	15.15	. . .
9.5	4.45	5.5	5.9	2.75	6.15	4.9	. . .
4.75	0.75	0.95	0.8	0.95	0.9	1.3	0 – 5
2.36	0.75	0.5	0.45	0.55	0.3	0.7	. . .
Pan	0	0	0	0	0	0	. . .

Figure 1: Concrete ingredients

Figure 2: Demolished waste and recycled aggregates

Recycled aggregates

Demolished waste used in this research study was collected from demolishing of five structural members, i.e., slab (RA-S), beam (RA-B), column (RA-C), footing (RA-F), and lintel (RA-L) from the vicinity of Nawabshah and Hala cities, Sindh, Pakistan. Large blocks of the waste were brought to laboratory and hammered down to maximum of 25 mm size (Figure 2). Each group of aggregates was treated separately in same way. Obtained aggregates were sorted for organic matter and cracked particles followed by washing and drying for 24-hours. Sieve analysis of all groups of the aggregates was done to ensure well graded aggregates in concrete. The obtained results are listed in Table 3. It may be observed that percentage passing of the aggregates is in good agreement with those of conventional aggregates. Also, percentage passing of both conventional and recycled aggregates fall within the specified range of relevant ASTM standards.

Fly ash

Fly ash used in this work was obtained from Lakhra coal mines as by product of burning of coal. The physical and chemical properties of the material were taken and considered from another work of the author [25]. Both physical and chemical properties of ash confirmed it in line with ASTM C618 [26] as class C-fly ash.

Figure 3: Fly ash

Figure 4: Testing of specimens

Preparation of specimens

To prepare the specimens of proposed concrete 1:2:4 mix with 0.5 water cement ratio was used. The mix was selected as it is commonly used in most of structural members in the industry. Replacement of conventional aggregates was done in 35% dosage following the conclusion of Bhatti [25]. Conventional coarse aggregates were used in 65% dosage. Lucky cement and hill sand were used as ordinary Portland cement and fine aggregates. Fly ash was used in the dosage of 0 to 15% with increment of 2.5%, thus making seven mixes (B1 to B7) in each group of recycled aggregates.

In each source of recycled aggregates and each dosage of fly ash fifteen samples are prepared. Out of prepared samples equal number (5) of samples is cured for 7-, 28-, and 90-days. Thus, in one source of recycled aggregates 35 samples for one curing age are prepares. Making it 105 samples for one source. Hence total of 525 samples are prepared for all five sources of recycled aggregates considered. Additionally, 15 samples of conventional concrete (CC) are also prepared to compare the results of proposed concrete. Altogether total of 540 samples are prepared.

Batching of concrete ingredients was done by weight batching. Mixing was done in pan mixer first in dry state followed by adding the required quantity of water and running the mixer till uniform paste was achieved. Standard size cylinder molds (6"/12") were prepared by oiling the inner surface, followed by filling in three layers. Compaction was done by table vibrator till slurry covered the top surface. After 24-hours samples were de-molded and allowed to dry for 24-hours at room temperature. Then all the samples were allowed for water curing for respective curing age.

Testing of specimens

After completion of respective curing age, samples were taken out of water and allowed to air dry for 24-hours in the laboratory. Followed by the samples were tested in universal testing machine under gradually increasing load at the rate of 0.5 kN/sec till crushing of the samples. Few samples are shown in Figure 4. Crushing load was recorded. The compressive strength was calculated by dividing the maximum sustained load with cross-sectional area of the sample. The compressive strength of samples of all sources of recycled aggregates for 7-day curing are plotted in Figure 5 to Figure 9. Similarly, the compressive strength results of 28-day cured samples for all sources are shown in Figure 10 to Figure 14 and Figure 15 to Figure 19 shows the compressive strength results of 90-day cured samples for all sources of recycled aggregates.

Results and Discussion

Compressive strength results presented earlier shows good correlation within samples in a source of recycled aggregates. Percent deviation in the results of the samples within a batch was less than 15%. With increase in percentage of fly ash increasing trend in compressive strength may be observed up to 10%. Beyond this percentage the compressive strength decreases. The results of individual samples in each batch of all sources are averaged. The average values for 7-, 28-, and 90-day cured samples are shown in Figure 20 to Figure 22. Similar trend may be observed from these figures.

7-day cured samples without fly ash observed decrease in compressive strength than conventional concrete. But the addition of fly ash improved the strength property. At the dosage of 2.5% compressive strength was better than the concrete without fly ash but remained less than conventional concrete. At 5%

replacement level compressive strength nearly approached the results of control concrete. At 7.5% dosage of fly ash most of samples reached the results of control concrete with two samples having strength results more than those of control concrete. The same trend continued with 7.5% dosage and maximum samples showed strength more than that of control concrete. At 10% dosage all the samples observed higher results than control concrete. But beyond this dosage the samples observed reduction in compressive strength. Indeed, it is due to the development of gel with hydration process which improves the bonding capabilities between ingredients of concrete. But beyond certain dosage the inside temperature of the concrete due to hydration process destroys the bonding capabilities resulting in lesser strength of the product.

Almost similar trend for 28-day and 90-day cured samples may be observed from the relevant figures but with lesser values of compressive strength. Again, at replacement level of 10%, the specimens showed better results than control concrete. This shows that early strength gaining capability of concrete with fly ash is more compared to later curing ages.

Comparing the effect of source of recycled aggregates on compressive strength it is observed that for all curing ages the recycled aggregates from column concrete performed better than its other counterparts. For 7-day cured samples (fly ash dosage of 10%) made with recycled aggregates from column concrete showed 10.14% increase in compressive strength than control concrete. The samples cast with recycled aggregates from other sources showed increase in strength from 2.7% to 7.6%. Similarly, 28-day cured samples cast using recycled aggregates from column concrete showed 17.07% increase in compressive strength. The other counterparts showed strength increase in the range of 6.76% to 11.06%. Like other curing ages, 90-days cured samples cast with recycled aggregates from column concrete showed improvement in compressive strength results with 10.04% increase in compressive strength. Whereas samples cast with recycled aggregates from other structural members observed change in compressive strength from -4.3% to 3.6%. Hence it is evident that at all curing ages recycled aggregates from column concrete performed well compared to recycled aggregates from other structural members. Also, it is observed that the optimum dosage of fly ash is 10% irrespective of the source of recycled aggregates. All concrete samples showed improvement in compressive strength at this dosage level of fly ash.

To demonstrate the effect of mixed aggregates on compressive strength, the results of all sources in a batch are averaged and plotted in Figure 23 versus the curing age. It may be observed that with mix aggregates 7- and 90-day cured samples showed better results than control concrete at 10% replacement of fly ash, whereas the 28-day compressive strength remained little less (-5.6%)than that of control concrete. Maximum gain in compressive strength is observed in 7-day cured samples with increase in strength equal to 6.97%. The increase in strength was recorded equal to 1.11%. As 28-day curing is standard, thus comparing it with elongated curing it may be said that elongated curing has positive impact on the strength but since different in strength with respect to control concrete is less than 5% thus it may be ignored, and 28-day curing may only be considered.

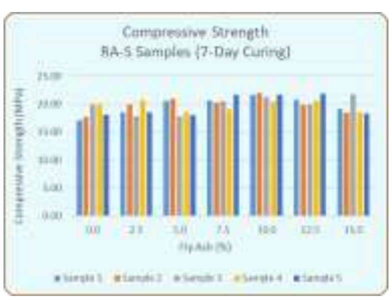

Figure 5: CS of RA-S (7d curing

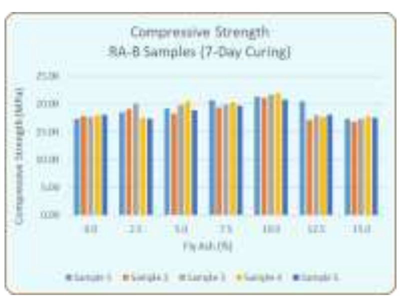

Figure 6: CS of RA-B (7d curing)

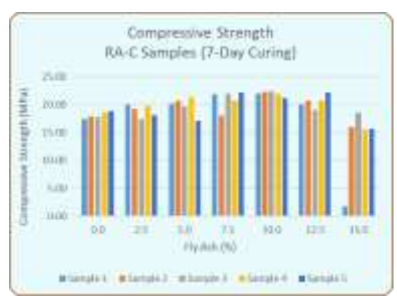

Figure 7: CS of RA-C (7d curing)

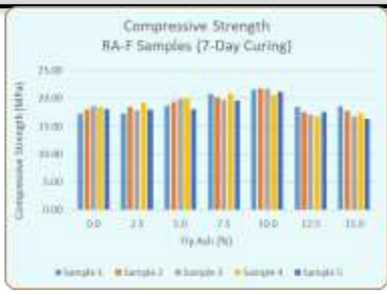

Figure 8: CS of RA-F (7d curing

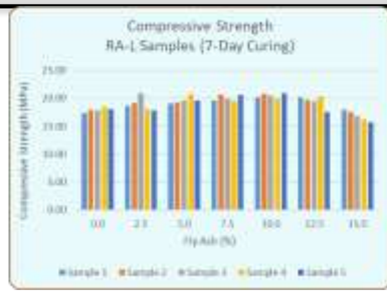

Figure 9: CS of RA-L (7d curing)

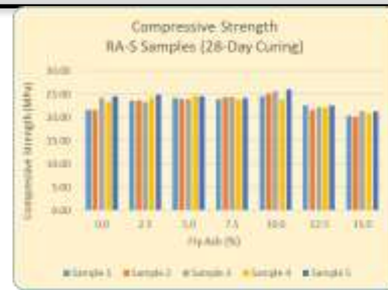

Figure 10: CS of RA-S (28d curing)

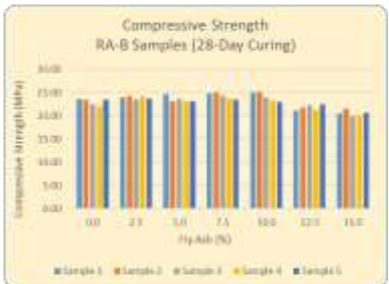

Figure 11: CS of RA-B (28d curing)

Figure 12: CS of RA-C (28d curing)

Figure 13: CS of RA-F (28d curing)

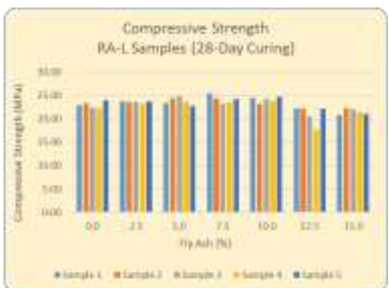

Figure 14: CS of RA-L (28d curing)

Figure 15: CS of RA-S (90d curing)

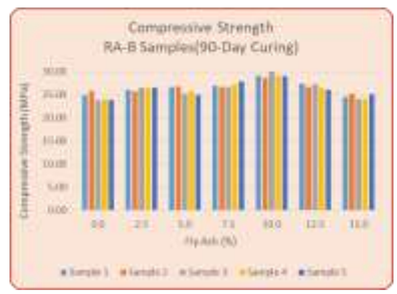

Figure 16: CS of RA-B (90d curing)

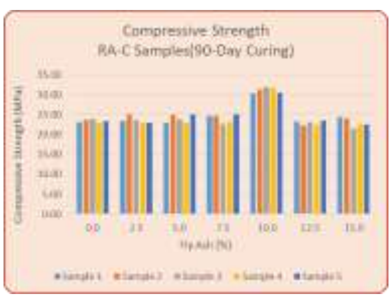

Figure 17: CS of RA-C (90d curing)

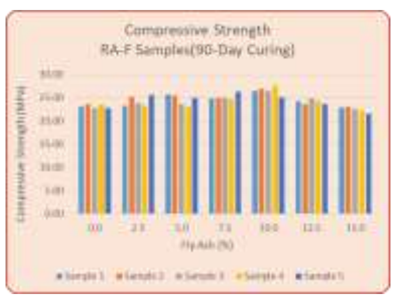

Figure 18: CS of RA-F (90d curing)

Figure 19: CS of RA-L (90d curing)

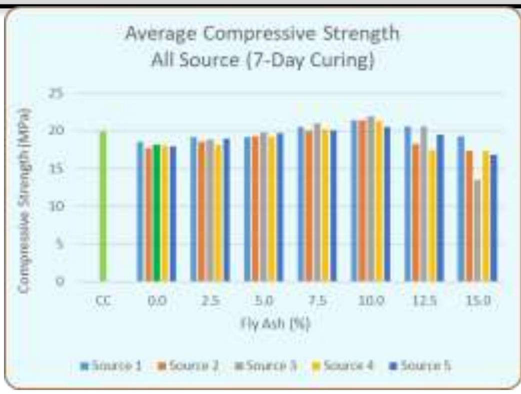

Figure 20: Average CS (7d curing) – all sources

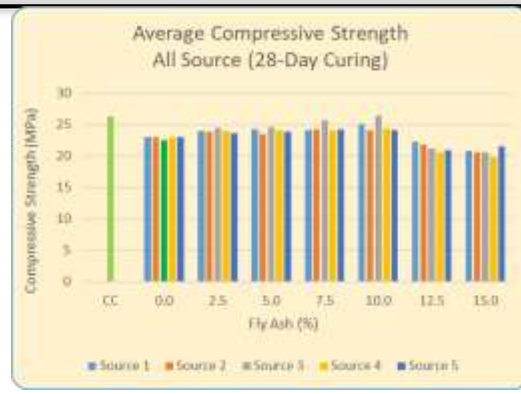

Figure 21: Average CS (28d curing) – all sources

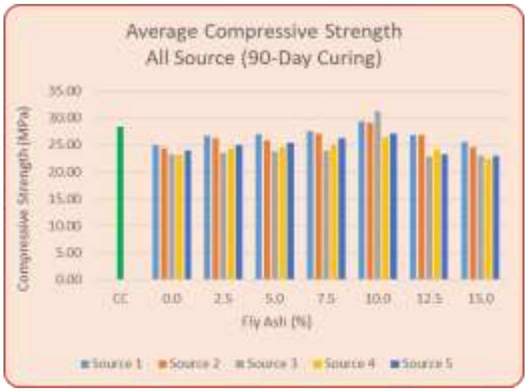

Figure 22: Average CS (90d curing) – all sources

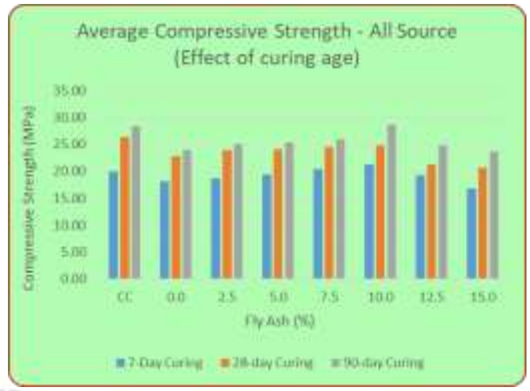

Figure 23: Average CS – Effect of curing age

Conclusion

In this research study laboratory investigation on effect of recycled aggregates from different structural members and fly ash is presented. Based on the outcome of the study following are concluded

Use of recycled aggregates alone has negative impact on compressive strength of the concrete.

Addition of fly ash improves the compressive strength but up to 10% dosage beyond which strength reduces.

At 10% dosage 7-day cured samples observed 10.14% increase in compressive strength than conventional concrete.

At the same dosage 28-day cured samples observed 17.07% increase in compressive strength than conventional concrete.

At 10% dosage elongated cured (90-days) samples observed 10.04% increase in compressive strength than conventional concrete.

Comparison of recycled aggregates from different structural members showed that recycled aggregates from column concrete performs better than recycled aggregates from other structural members.

Effect of curing revealed that maximum gain in compressive strength is at 28-days. At elongated curing only 5.8% increase in strength than 28-day cured samples is observed.

Checking of mixed aggregates showed increase in compressive strength at 7-, and 90-day curing whereas about 6% decrease was recorded for 28-day cured samples. Therefore, it should be noted that with mixed aggregates elongated curing gives better results.

Although class C-fly ash is used in this study yet its performance in terms of compressive strength is evident.

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