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Effect of recycled aggregates with different parent strength and fly ash on flexural strength of recycled aggregate concrete prisms

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K E Y W O R D S

Demolishing Waste

Recycled Aggregates

Parent Concrete Strength

Fly Ash

Flexural Strength

Concrete Prisms

A B S T R A C T

Fast consumption of conventional ingredients of concrete and waste generated due to demolishing old buildings is a multi-fold problem in the concrete industry. Hence the sustainable alternative of it is the need of the day. In this research work effect of binary blending of demolished waste and fly ash on the flexural strength of plain concrete prism is presented. The properties of aggregates and cement are evaluated. The physical and chemical properties of fly ash were determined. Recycled aggregates from demolished waste with different mix ratios (1:2:4 and 1:1.5:3) were used. Optimization of recycled aggregates; by evaluating concrete cylinders in 12 batches; showed 35% as optimum. At the optimum dosage of recycled aggregates fly ash was used from 2.5% to 15% with an increment of 2.5% to optimize its dosage. Compressive strength test of the standard-size cylinders and their comparison with control concrete showed a 10% dosage of a fly as the optimum percentage to replace the cement in the concrete matrix. Using both optimized dosages of recycled aggregates and fly ash prism specimens of 900mmx150mmx300mm were cast in four batches. The beam specimens were cured for 28 days followed by an evaluation of flexural strength and deflection under centric load in the universal testing machine. Test results of flexural strength (only 15% loss) showed good potential for both waste materials in the concrete matrix. Recycled aggregate with higher parent strength showed better performance than its other counterparts. With higher-strength recycled aggregates residual flexural strength was recorded as equal to 93%. For all specimens recorded deflection was within the allowable limits of ACI-318.

1. Introduction

Changes in social trends, the standard of living, and minimization of hazardous effects and pace of development around the world require the construction of new and innovative buildings. The boom of construction since near th past is evidence of the same. To meet the needs of the infrastructures and associated facilities, particularly in urban areas due to the urbanization of people from rural areas, growing population of the areas, modernization, etc. new construction is unavoidable. However, scarcity of space in the urban centres forces the industry to opt for vertical expansion and demolition of old and deteriorated structures. The phenomenon on the one hand consumes conventional sources of aggregates at a faster pace and on the other hand proves harmful to the environment due to the excessive running of relevant industries [1]. Consumption of cement; 4.4 billion tons; only in China during 2020 – 2021 is reported. This amounts to more than the cement consumed by the US in the 20^{th} century [37]. It in turn generates harmful flue gases which disturbs the environment and thus the health of the inhabitants. Another issue associated with the boom of construction is the demolishing of the old, deteriorated, short height structures. To this end only in Finland about 51 thousand buildings were demolished from 2000 to 2012 [38]. The demolishing generates a huge quantum of waste, and it is increasing with each passing day. Generally, this waste was dumped in landfills but the space scarcity in urban areas has posed additional problems of dumping the waste. Transportation of it to far areas casts additional funds posing an extra burden on the project and leaving it unattained poses serious problems to surroundings of the project and the environment. In some cases, it is dumped in the outskirts of the city. It not only destroys the aesthetic view but in the case of agricultural lands, it poses a serious issue of disturbance and wastage of agricultural aspects of the land.

To deal with this multi-fold problem of demolishing waste a solution is to reuse it in the new concrete. It not only conserves the conventional sources of concrete ingredients but also helps in protecting the environment and developing of indigenous green concrete. This meets the older desire of researchers to find an alternative to conventional concrete ingredients. It is also evident from the review work of Nehal [36] that the research publication on the use of demolishing waste up to 2006 was less than 16 per year but it increased to about 213 per year in 2020 and 2021. The usage of demolished waste in concrete has been carried out by many researchers for all three constituents of concrete. But as the coarse aggregates take up more volume of the concrete body in comparison to other constituents, therefore, usage of demolishing -waste as coarse aggregate is more practical [1,2]. It consumes more waste thus reducing the waste management burden and negative impacts on the environment to some extent.

Another type of waste that results from coal burning is fly ash [21,22]. It is available worldwide in huge quantum and has the capability to replace the cement in concrete matrix. When fly ash material is added in concrete it reacts with calcium-hydroxide and forms calcium hydrated-silicate gel. Thus, it has the capabilities to partially replace the cement in a concrete matrix. This replacement will not only lessen the burden on the cement industry thus reduces the negative impact on the environment but also make use of the waste material which in turn lessens the waste management burden. Individually recycled aggregates and fly ash have been attempted in concrete and coarse aggregate replacement and cement replacement respectively but the combined use of the materials in the concrete matrix is seldom especially use of recycled aggregates with different parent strengths. Also, the scatter in reported results shows the need for more work in the area. Therefore, this research program aims to evaluate the effect of the combined use of recycled aggregates with different parent strengths and fly ash on the flexural strength of binary green concrete. Different structural members will be used to produce the recycled aggregates and will be used as partial replacement of coarse-aggregates whereas cement will be partially replaced by fly ash. Concrete prisms will be tested for flexural behaviour. Obtained results will be compared, and analysed.

2. Literature Review

This section provides the review of already published articles relevant to proposed topic. The demolishing waste earlier was used under floors and plinth but even then, the residual amount of the waste was large. The use of demolishing waste in new concrete is not new. Several components, i.e., glass, bricks, concrete, etc. have been tried in concrete as partial or full replacement of cement, (fine and coarse) aggregates. Review articles on the use of demolishing waste [1] – [4] highlights the problems associated with the aggregates along with need of the promotion and regulations to make use of the same. The use of demolishing waste from different sources on basic and strength properties of concrete has been studied by Abera [5]. Based on the results author argues that the compaction rate of recycled aggregate concrete is higher which leads to several problems. Also, the author found that up to 35% replacement of conventional aggregates with recycled aggregates compressive strength reduction in only 30% and no massive damage to light weight works if the conventional coarse aggregates are replaced with recycled aggregates up to 40%. Similar reduction in compressive strength and optimum dosage (40%) was recorded by Khatab et al. [6] while using the demolishing waste from war destroyed building of Iraq as coarse aggregate in new concrete. In another research work Neha et al. [7] found only 7% less compressive strength when 40% replacement of conventional coarse aggregates was made. Alam et al. [8] has also attempted recycled aggregate in new concrete as replacement of both fine aggregates and coarse aggregates along with silica fume as cement replacement up to 6%. From the obtained outcomes of compressive, tensile, and flexural strength authors observed 9%, 18% and 24% reduction respectively for 28 day cured samples. Goumathy et al. [9] used demolished concrete as coarse aggregates up to 30% along with superplasticizer to control the workability and found 4%, 32% and 3% reduction in compressive, tensile, and flexural strength of the concrete. Ghosn et al. [10] also tried to advance the properties of recycled

-aggregate concrete (50% RCA) by consuming hemp fibers of 20mm and 30mm length. Test results of compressive, tensile, and flexural strength showed 30%, 10%, and 50% reduction. Halahla et al. [11] on other hand observed 10% and 5% reduction in compressive and tensile strength of recycled aggregate concrete. Thus, the authors argues that the behavior of recycled aggregate concrete is like conventional concrete hence is possible to use in structural members. Lianes et al. [12] observed 50% as optimum dosage of recycled aggregates in new concrete and concluded that the concrete is environment friendly and has tensile strength even better than conventional concrete in some cases. Research findings of Mahakud et al. [13] for compressive, tensile, and flexural strength of recycled aggregate concrete shows much better results than others as they observed 25.7%, 2.39%, and 3.22% reduction strength parameters respectively.

Durability of concrete is one of its important aspects for safety and serviceability. To this end Nakhi and Alhumoud [14] developed recycled aggregate concrete using coarse aggregates from demolished concrete up to 100% dosage to test chloride diffusion and penetration. The test results of concrete samples exposed to chloride solution for two and four weeks showed the authors least penetration at 40% dosage of the demolishing waste as coarse aggregates. Nakhi et al. [15] also did not found any remarkable effect on durability of recycled aggregate concrete beams. Additionally, they also observed similar crack pattern in recycled aggregate concrete. Abdollahnejad et al. [16] based on their research finding states that defects and pores of recycled aggregates are problem towards durability. While studying alkali activated recycled aggregate concrete authors observed that high calcium-concentration affects the binder gel and accelerate the hydration amount of concrete thus lessens flowability of alkali activated concrete. Rashid and Mohammed [17] used demolished waste from Turkey in new concrete as coarse aggregates up to 100% to study the flexural behavior of RC beams. The authors found from test results 10% and 34% reduction in stiffness and toughness of the concrete. They also observed that the proposed concrete crack faster than conventional concrete, thus proper measures should be taken before using it in structural members. Arul et al. [18] studied impact resistance of green concrete of grade M25. They developed this concrete using recycled aggregates, 10% silica fume, PPF, and coir fibers. From laboratory investigations they found good resistance of concrete against impact loading. The authors attribute it to silica fume and fibers. Use of silica fume in recycled aggregate concrete has also been made by Lesovik et al. [19], where in the authors observed good increase in both compressive and tensile strengths due to presence of silica fume in comparison to recycled aggregate concrete without silica fume. Zuki et al. [20] attempted epoxy treatment to recycled aggregates to improve the properties of recycled aggregate concrete. The authors used epoxy from 0 to 100% with increment of 25% to treat the recycled aggregates before using them in concrete. From the laboratory study of the proposed concrete samples researchers resolved that the low usage of resin result in good strength of the product. The residue of coal burning is known as fly ash and is available almost everywhere in world in bulk quantities. It is waste and need proper treatment and dumping to avoid unpleasant view and hazard to environment and health of inhabitants. The process not only require space but also puts extra burden on the project. On the other hand, amplified demand of cement has caused resource depletion. It also damages the environment to much extent due to huge emission of carbon dioxide as the cement industry is running for more time. Therefore, the researchers around the globe are continuously working to find alternatives of the cement for concrete matrix. Fly ash is one among them and has been attempted in concrete by various researchers [21]. It also has been used as mineral admixture in concrete matrix to improve its properties. Literature reports that the fly ash has capabilities to replace cement even up to 60% [22]. Considerable improvement in strength properties of concrete have been reported by Bendapudi and Saha [23] among many others. Fly ash has also been attempted in high strength conventional concrete by Nath and Sarkar [24]. Induction of fly ash increased strength and reduced sorptivity of 28-day cured samples of the concrete. Jatale et al. [25] used fly ash in the dosage of 20%, 40%, and 60% to develop, M15, M20, and M25 concrete. From the obtained results the authors developed curves to check fly ash dosage based on basic and strength properties. To develop cement free concrete authors in [26] used 100% fly ash with alkaline solution to prepare concrete specimen. Laboratory investigations showed the authors good correlation between results of proposed and conventional concretes. Contrary to above Helepciuc et al. [27] observed from the test results of concrete with 10% to 30% of fly ash that the compressive strength is badly affected. However, they also observed that 20% replacement of cement with fly ash proves good for tensile strength and durability of the concrete.

Fly ash has also been attempted in recycled aggregate concrete to check its effect on compressive strength by Chandio et al. [28]. 50% replacement of conventional aggregates with 0-10% in increment of 2.5% fly ash was used to prepare samples for compressive strength evaluation. Based on the laboratory results writers concluded 2.5% dosage of fly ash in recycled aggregate concrete (with 50% dosage of RCA) as optimum as at the dosage level strength reduction in comparison to conventional concrete was only 11%. Fly ash has also been used in self-compacting concrete. Low strength SCC developed by Fernando et al. [29] by using reduced cement content, fly ash and metakaolin. Based on the laboratory outcomes authors argued that the use of fly ash and metakaolin is very useful in producing low strength self-compacting concrete with desired workability. Pathak et al. [30] used fly ash as mineral admixture in the dosage of (0%, 30%, 40% and 50%) to develop SCC. The prepared concrete specimens were exposed to elevated temperatures equal to (20°C, 100°C, 200°C and 300°C). Strength test results showed the authors that compressive strength was from 21.43 MPa to 40.68MPa, whereas the tensile strength was in range of 1.35 MPa to 3.60 MPa. Both sets of results were better compared to conventional concrete in same conditions. The authors also observed that compressive strength was remarkable at 200°C to 300°C, but the tensile strength was somewhat reduced when temperature was elevated above 20°C. Memon et al. [31] used fly ash and crushed and un-crushed aggregates in development of self-compacting concrete to test its fresh and hardened properties. Laboratory investigations revealed the authors better fresh properties but depends on the dosage of the fly ash. At the same dosage of fly ash compressive strength was recorded equal to 64.58 MPa and 58.05 MPa for crushed and un-crushed aggregates respectively. Therefore, the authors concluded that the dosage of fly ash plays vital role in enhancing the properties of self-compacting concrete whereas crushed aggregates give better strength properties than un-crushed aggregates which otherwise are better for better flowability of the concrete.

Huseien et al. [47] in their research program studied compressive strength and micro structural properties of concrete made with effective microorganism and fly ash. Using four ratios from 5 to 20% with increment of 5% authors observed betterment in both parameters of study. Particularly at 10% dosage of microorganism 30% increase in compressive strength was recorded. Evaluation of micro structure of the concrete using XRD, EDM, SEM, TGA, and DTG protocols less pores and better morphology of the concrete was observed. Hence authors concluded their work with argument that proposed concrete is not only environmentally friendly and less contributor towards global warming but also is an effective alternative of the conventional concrete.

Huseien et al. [48] in another research work studied bond strength properties of geopolymer mortars with high volume GBFS, fly ash, and palm oil fuel ash. Slag was used in the dosage of 50%, 60% and 70% to study its effect on geopolymerization process and strength performance. Bond strength was studied using slant shear, flexural and tensile strength, whereas, mineral properties were evaluated using XRD, ESM and FTIM protocols. At the highest dosage of slag geopolymerization process was observed reduced. It was then balanced by lower dosage of slag to 50% and the difference with fly ash. The authors thus observed better surface morphology, less porosity and lesser unreacted particles. Hence the proposed mortar was concluded in line with conventional concrete.

Algaifi et al. [49] also used high volume fly ash along with slag and palm oil fuel ash but studied durability and performance of alkali-activated mortars using surface methodology approach. A ternary binder system using fly ash at 50%, 60% and 70% dosage with slag and palm oil fuel ash from 0 to 30%. Compressive strength and microstructure with freeze-thaw cycles, wet-dry cycles and acidic environment were studied for one year. The test results showed the authors that at the dosage of 60% (FA), 10% (palm oil fuel ash) and 30% (GBFS) was optimum with enhanced performance of the study parameters.

From above discussion it may be observed that research community around the globe have devoted time and effort in understanding the behavior of the demolished waste in new concrete. But the scatter in results and better understanding of various aspects still need more work to reach certain level of confidence in using the material. Although both materials have been used in concrete, the combined use is very less particularly towards the flexural behavior using demolished concrete waste with different parent strength. Therefore, this research study proposes the evaluation of flexural behavior of binary blended concrete with recycled aggregates having different parent strength and fly ash.

3. Material and Testing

3.1 Cement

The cement used in this research work is an ordinary Portland cement, a brand-named Pak Land cement. The properties of the cement were evaluated and listed in Table 1. The properties of cement are in accordance with the ASTM C150 [39] standards. A sieve analysis of cement was performed and is shown in Fig. 1. It may be observed that all the properties of the cement are within the specified range of the relevant ASTM standards [39].

Table 1

Cement properties

#	Property	Value
1	Specific surface area	382 m^2/kg
2	Setting time (Initial)	173 min
3	Setting time (Final)	228 min
4	Consistency	31
5	Loss on ignition	2.1%

3.2 Fly Ash

Fly ash used in this research work is obtained from Lakhra coal mines. The pictorial view of the material is shown in Fig. 2. The physical properties of the material were checked and are given in Table- 2. The chemical analysis of the material using EDS were determined and are given in Table 3 and shown in Fig. 3. It may be perceived that the sum of SiO2 + Al2O3 + Fe2O3 = 26.45 + 19.7 + 4.9 = 46.05 which satisfy the standard requirement (less than or equal to 50) of ASTM C618 [41] for class-F fly ash. The results presented in Fig. 3 are found in good agreement with the similar results presented by Memon et al. [31]. Physical properties of the fly ash were also found as per ASTM C618 [41]. Further the sieve analysis of fly ash like cement was done and is shown in Fig. 1. It is done to ensure the fineness of fly ash in line with that of cement as the finer particles contributes better to the strength of concrete through hydration process and bonding. The graph is plotted along with the graph of cement to compare both sets of the results. It may be observed from the Fig. that the fineness of the fly ash is less compared to cement, but it is within the allowable ASTM ranges (Fineness ≤ 34) [41].

Table 2

Fly ash (Physical properties)

#	Property	Value
1	Fineness (45-micron sieve)	<30% retained
2	Colour	Blackish Brown
3	Specific gravity	2.1
4	Moisture content	0.61
5	Loss on Ignition	1.9

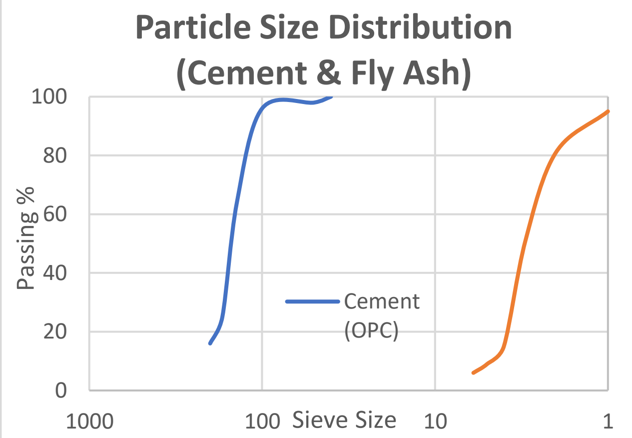

Fig. 1. Particle Size Distribution

Table 3

Fly ash (Chemical properties)

#	Chemical	Value
1	Silicon Oxide (SiO_2)	21.45
2	Aluminium Oxide (Al_2O_3)	19.7
3	Magnesium Oxide (MgO)	0.83
4	Calcium Oxide (CaO)	2.41
5	Iron Oxide (Fe_2O_3)	4.9
6	Potassium Oxide (K_2O)	2.12
7	Sulphur Trioxide (SO_3)	0.11
8	Titanium Dioxide (TiO_2)	1.64

Fig. 2. Fly Ash

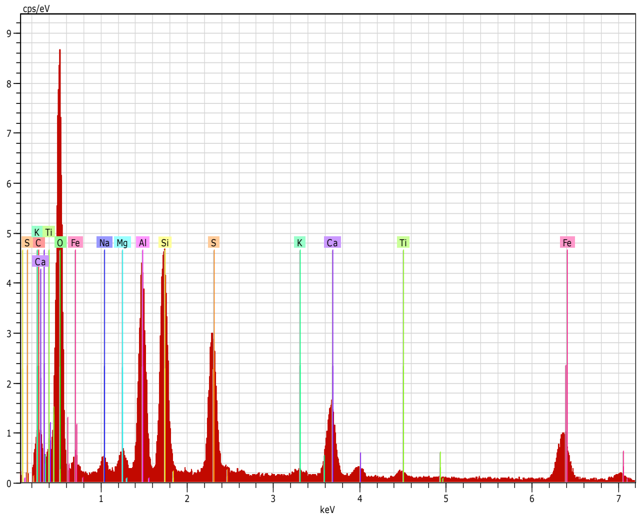

Fig. 3. EDS Analysis Of Fly Ash

3.3 Sand

The sand used in this study is hill sand obtained from approved sources. The basic properties of the sand were evaluated and are listed in Table 4. Sieve analysis of the aggregate was done to ensure it quality in accordance with relevant ASTM C136 [40] standards and is shown in Fig. 4. The percentage passing on each sieve in within the allowable limit of relevant ASTM standards.

Table 4

Properties of sand

#	Property	Value
1	Fineness modulus	3.97
2	Density (Kg/m^3)	2481
3	Water absorption (%)	1.38
4	Specific gravity	2.41
5	Loss on ignition	1.71

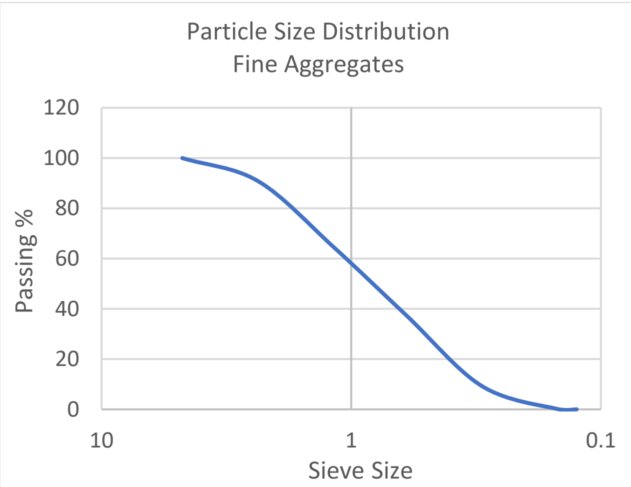

Fig. 4. Particle Size Distribution Of Sand

3.4 Coarse Aggregates

Maximum 25mm size of conventional coarse aggregates were used. The coarse aggregates obtained from approved quarry of government of Pakistan were first washed and dried, then basic properties of the aggregates were determined and are listed in Table 5. Sieve analysis of the aggregates was also performed to confirm well -graded aggregates in concrete mix [40]. Same result is shown in Fig. 5. It can be seen from the Fig. that the pattern of all the curves is same with minor deviation. In fact, it is due to manual processing of the demolishing waste, which in turn result in minor deviation in different sized coarse aggregates.

Large blocks of demolishing waste were collected from demolishing of residential building of Hala City, Sindh, Pakistan. The debris were collected from different structural members separately as per details shown in Table 6. The large blocks (Fig. 6) were manually hammered down to maximum of 25 mm size (Fig. 7) followed by sorting for unwanted substances (cracked particles and organic substances), washing and drying. Analogous to conventional aggregates, recycled aggregates were also sieved to confirm it as well graded. Fig. 4 shows the percentage passing results of recycled aggregates on various sieves.

Surface texture of both conventional and recycled aggregates was examined. Closer view of the aggregates is shown in Fig. 8. Surface of the conventional aggregate is smooth, crack, and pores free whereas the surface of recycled aggregates was rough and porous. Also, the mortar is observed attached with the coarse particles of the aggregates. The old mortar attached, and porous nature of the aggregates give rise to the water absorption of the aggregates, and it need to be adjusted while deciding the water cement ratio of the mix. It may be observed that water absorption of RC1 (Recycled Aggregates from Beam, Slab, Lintel and Footing) and RC2 (Recycled Aggregates from Column) aggregates is 239% and 242% more than ordinary aggregates. It is due to the age and pores of old concrete. The values are 72% and 42% less than the values reported in reference [34] and reference [35].

The specific gravity of recycled aggregates is 17% (for RC1) and 14% (for RC2) less than that of conventional aggregates. Also, it is about 5% higher than the result of same parameter given in reference [34] and [35]. The deviation in the results of other parameters is not much except the impact value and abrasion which are higher compared to the conventional aggregates due to age of concrete and old mortar adhered with the aggregates.

Table 5

Properties of coarse aggregates

#	Property	Conventional Coarse Aggregates	Recycled Coarse Aggregates	
			RC 1	RC 2
1	Water absorption (%)	0.99	2.37	2.40
2	Specific gravity	2.63	2.17	2.25
3	Fineness modulus	5.1	5.2	5.3
4	Impact value	12.3	21.4	20.3
5	Crushing value	18.2	26.4	23.7
6	Density (Kg/m^3)	1688.74	1482.40	1362.12
7	Unit weight (Kg/m^3)	1590.50	1382.60	1290.80

8	Soundness (%)	4.98	6.92	6.82
9	Abrasion (%)	7.2	22.8	20.1

Table 6

Demolished waste

#	Source	Designation	Ratio	Strength (MPa)
1	Beam, Slab, lintel, footing	RC1	1:2:4	30
2	Column	RC2	1:1.5:3	40

3.5 Mix Details And Sample Preparation

After evaluation of the basic properties of the ingredients, dosage of the recycled aggregates is optimized. The recycled aggregates are used in the dosage of 0%, 5% to 95% with increment of 10% and 100%. Concrete with 0% Recycled Concrete Aggregates (RCA) was treated as control mix to compare the result of recycled aggregate concrete. Total of 12 batches (B1 – B11 and CM) with 5 cylinders of standard size (6"/12") in each batch were designed [43] for both groups of the aggregates (RC1 and RC2). Hence altogether 24 batches with 120 cylinders were designed. Mix ratio of 1:2:4 with water cement ratio equal to 0.5 was adopted in accordance with [46]. The mix ratio is selected as it is commonly used mix in field. Water cement ratio equal to 0.5 was used to give due consideration to the higher water demand of the recycled aggregates. The water used in preparation of concrete mixes is collected from water supply line of the city with pH value equal to 7.1.

The concrete ingredients were mixed in concrete mixer followed by filling the cylinder molds in standard fashion. The compaction of the cylinders was done by table vibrator. After 24-hours the cylinders were opened, and the specimens were left in lab for 24-hours to air dry. Thereafter, the specimens were cured for 28-days by fully immersing in potable water [43].

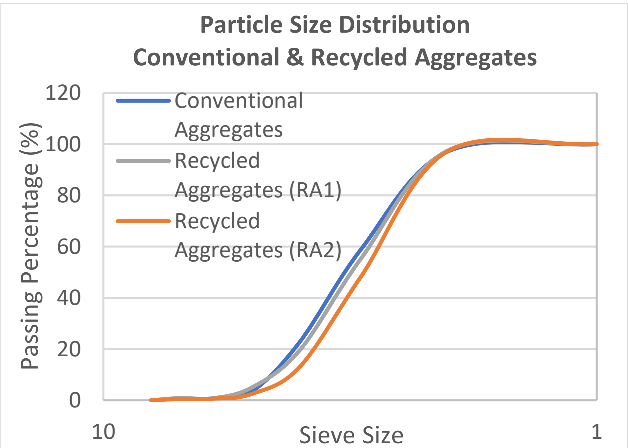

Fig. 5. Particle Size Distribution Of CA

Fig. 6. Demolished Waste

Fig. 7. Recycled Aggregates (Max. 25 Mm)

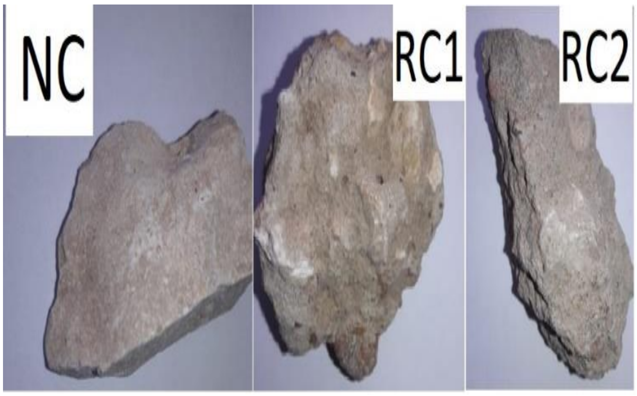

Fig. 8. Surface Texture Of Coarse Aggregates

4. Optimization of Recycled Aggregates

After elapsing of the curing time, specimens of all batches for both groups of aggregates were tested in universal testing machine for compressive strength in accordance with guidelines of ASTM C39 [45]. The loading rate of the machine was 0.5 kN/sec. The load was applied gradually till failure. Selected specimens are displayed in Fig.-9. The results of compressive strength of recycled aggregates RC1 and RC2 are shown in Figures 10 and 11. The obtained results were found better compared to those presented in references [28] and [34]. It was observed that increased dosage of recycled aggregates reduces the strength. Analysing average compressive strength of five samples in each batch of both groups of aggregates (Fig. 12), it may be observed that at 35% dosage of recycled aggregates reduction in strength is least compared to other dosages of recycled aggregates. At this replacement level the reduction in compressive strength is less about 15% for both groups of recycled aggregates. Further it may also be observed that strength results with RC2 aggregates is better compared to RC1. Although the difference between the two sets of results is about 1%, yet the improvement is there. Indeed, it is due to the better parent strength of concrete due to which the binding of the particles of the recycled aggregates is better. Considering the least reduction in compressive strength 35% dosage was concluded as the optimum dosage of recycled aggregates in this study . The obtained results wer also found better compared to those presented in reference [34]. The reduction in the compressive strength is attributed to the quantity of recycled aggregates and mortar attached to them. Due to increased quantum of these materials makes the coarse aggregates weak and thus reduces the strength of the concrete.

Fig. 9. Compressive Strength Test

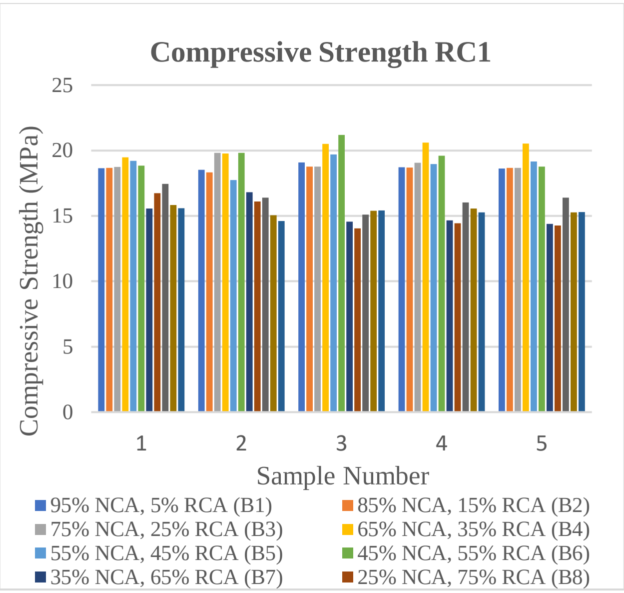

Fig. 10. Compressive Strength Of Concrete With RC1 Coarse Aggregates

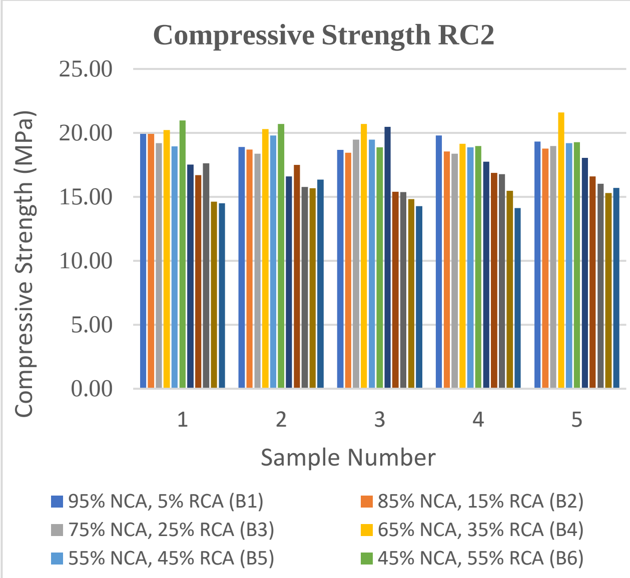

Fig. 11. Compressive Strength Of Concrete With RC2 Coarse Aggregates

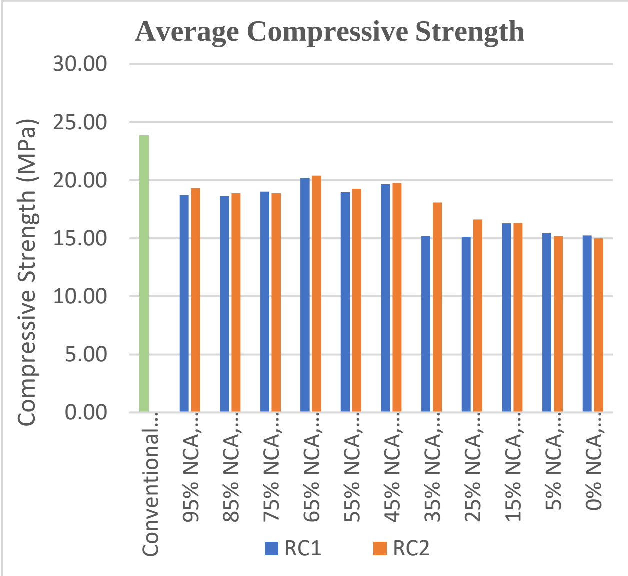

Fig. 12. Average Compressive Strength

5. Optimization of Fly Ash

Using the optimized dosage of recycled aggregates, optimization of dosage of fly ash was done. The fly ash was used from 0 to 15% with increment of 2.5%. The fly ash was used to replace the cement by percent weight. Total of 6 mixes with fly ash were designed for each group of aggregates (RC1 and RC2). In each dosage of fly ash 5 cylinders of standard size were prepared. Mix ratio and water cement ratio were used as explained earlier. Thus, total of 60 cylinders were prepared in standard fashion and cured for 28-days. After the end of curing time all the samples of both groups of aggregates were tested in universal testing machine in accordance with ASTM C39 [45] standards with machine details as explained earlier . The crushing load was recorded for each specimen then the compressive strength was determined by standard formula for compressive strength. Obtained results for recycled aggregate group RC1 and RC2 are plotted in Figures 13 and 14. The figures revealed that the compressive strength of individual samples within a group was having less than 15% deviation also the results were found better compared to those presented by Chandio et al. [28].

It was observed that within each dosage of the fly ash the compressive strength of the specimens is in good agreement to each other. Deviation in strength remained less than 15% of their mean value. The average strength of each batch was evaluated in is compared in Fig. 15 with average compressive strength of conventional concrete. Deviation of the compressive strength of binary blended green concrete of RC1 and RC2 with conventional concrete is plotted in Fig. 16 and Fig. 17.

It was noted from the figures that gradual increase in compressive strength with increase in dosage of fly ash is observed up to 10% replacement level. Beyond this dosage the compressive strength reduced and was recorded 14.03% less at 15% replacement level for concrete with RC1 aggregates and 13.69% less at same replacement level of cement with fly ash. The decrease in strength is due to the fact that quantity of cement replaced reduces the required quantity in concrete matrix. The fly ash beyond certain limit do not compensate the cement decrement. The increase in strength shows that the fly ash has capability to improve the strength property of recycled aggregate concrete. Also, it proves itself as the partial alternative of the cement in concrete matrix. The increase in strength is attributed to the filling ability of the fly ash which result in more compact product [24]. The fly ash fills the gap between coarse particles along with fine particles very well. Therefore, 10% of the fly ash is observed as optimum quantity to replace the cement with fly ash as at this replacement level the compressive strength is 4.6% and 10.7% higher than recycled aggregate concrete without fly ash for recycled aggregate group RC1 and RC2 respectively. Beyond 10% dosage the strength started degrading due to the reduced cement quantity thus may be the weaker bond between ingredients of concrete matrix . The reasoning beyond the phenomenon is same as stated earlier.

6. Flexural Strength

After optimizing the dosage of fly ash, four mixes were designed as per the details given in Table 7. In each mix, five prism specimens of 900 mm x 150 mm x300 mm size were prepared. In preparation of prism samples other concrete ingredients were used same as explained earlier. Prism moulds were made ready, filled, and compacted in accordance with ASTM C943 [43] (Fig. 18). After opening the moulds, specimens were cured for 28-days. After the end of the curing age, all the specimens were tested for flexural strength under a central point load in the universal testing machine (Fig. 19). The load was gradually applied till failure. During the testing deflection at centre was recorded at regular interval. From the recorded crushing load flexural strength was computed by using standard formula (f_s=3PL/2bd^2) for the purpose. Computed flexural strength for all specimens along with average is listed in Table 8. The average compressive strength is shown and compared in Fig. 20. The figure shows that induction of recycled aggregates affects the strength development but induction of fly ash result in improvement of the parameter. Comparing the results with those of conventional concrete reveals that introduction of recycled aggregates at optimized dose reduced the flexural strength by 11%. Addition of fly ash showed improvement in the strength by 3% than recycled aggregate concrete with RC1 aggregates and 5% with RC2 aggregates. The percentage deviation of flexural strength for RC1 and RC2 aggregates is shown in Figures 21 and 22. It is observed that total reduction in flexural strength of binary blended concrete with RC1 aggregates is about 10% whereas the same with RC2 aggregates is about 7%. This shows that recycled aggregates with higher parent strength performs well. In deed the higher parent strength, i.e., 1:1.5:3 was designed for higher strength of the concrete and the recycled aggregates produced from it also hold better strength than recycled aggregate obtained from 1:2:4 concrete. Further comparison of the results with those published in reference [35] revealed betterment of the flexural strength both at dosage level and due to induction of the fly ash.

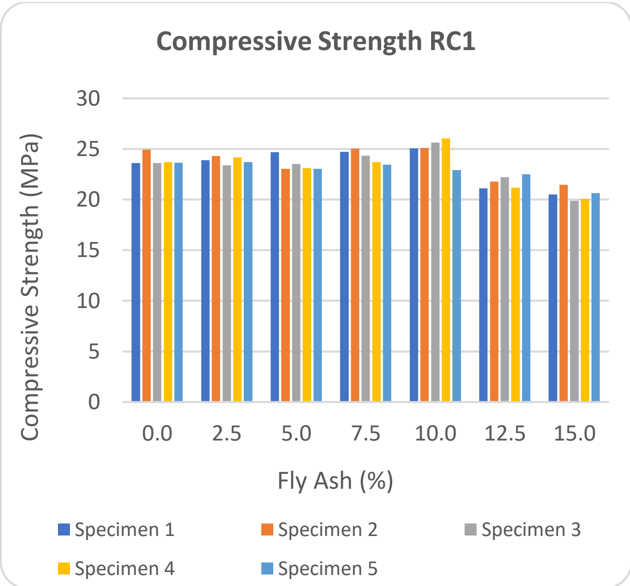

Fig. 13. CS Of RAC With RC1 Aggregates

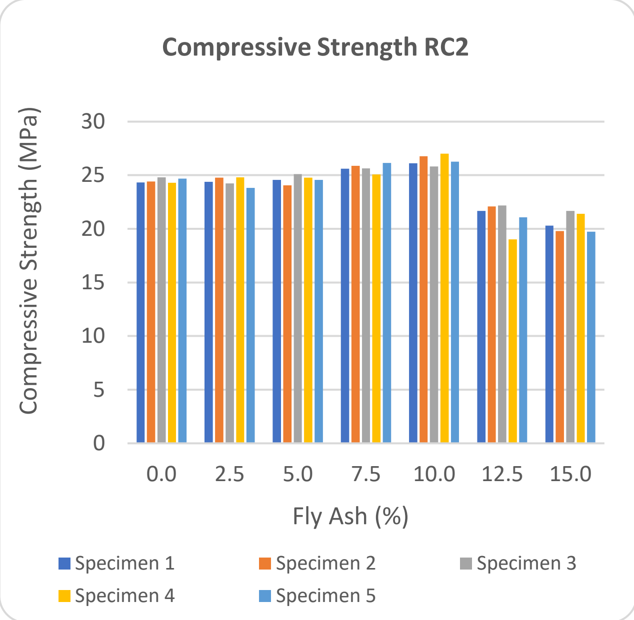

Fig. 14. CS Of RAC With RC2 Aggregates

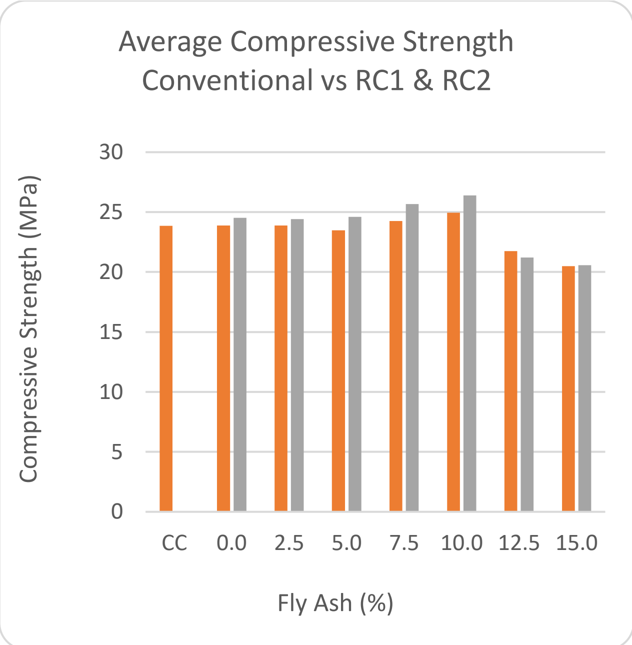

Fig. 15. Average Compressive Strength Of RAC

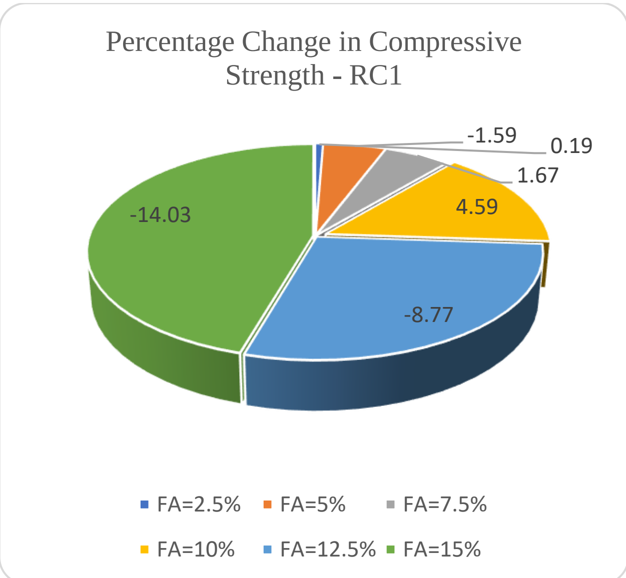

Fig. 16. Percent Deviation Of CS Of RAC – RC1

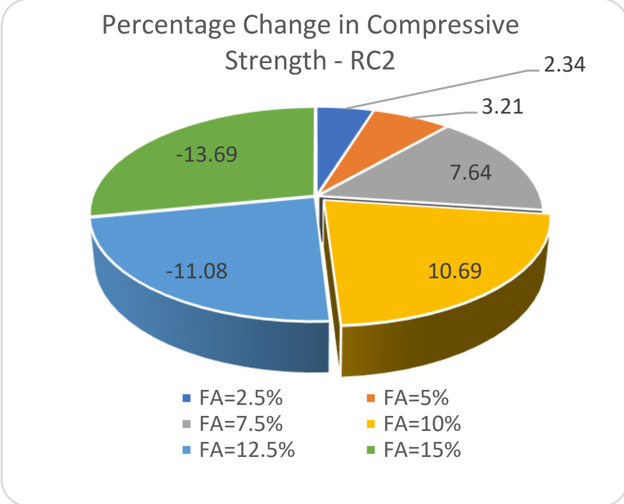

Fig. 17. Percent Deviation Of CS Of RAC – RC2

Table 7

Details of mixes for preparation of beam specimens

#	Description	Designation	Ratio	NCA (%)	RCA (%)	Fly ash (%)
1	Conventional concrete	B1	1:2:4	100	0	0
2	Recycled aggregate concrete	B2	1:2:4	65	30	0
3	Binary blended concrete Recycled aggregate source RC1	B3	1:2:4	65	35	10
4	Binary blended concrete Recycled aggregate source RC2	B4	1:2:4	65	35	10

Table 8

Flexural strength

Batch	Flexural Strength (MPa) for specimen					Average
	1	2	3	4	5	
B1	4.61	4.16	3.86	3.95	4.17	4.15
B2	3.81	3.83	3.82	3.50	3.50	3.69
B3	3.84	3.69	3.81	3.67	3.74	3.75
B4	3.87	3.96	3.91	3.61	3.97	3.86

Fig. 18. Beam Specimens

Fig. 19. Beam Specimen Testing

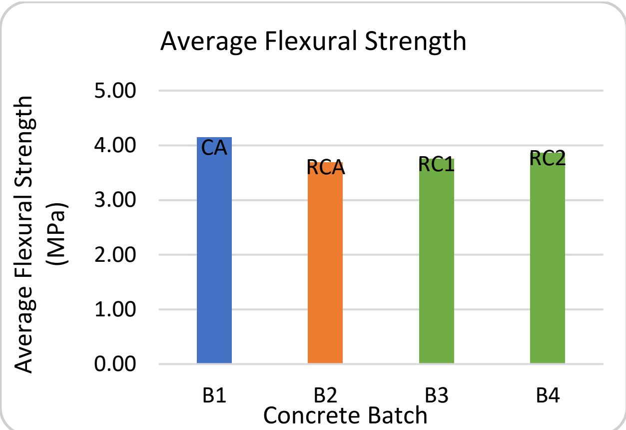

Fig. 20. Average Compressive Strength

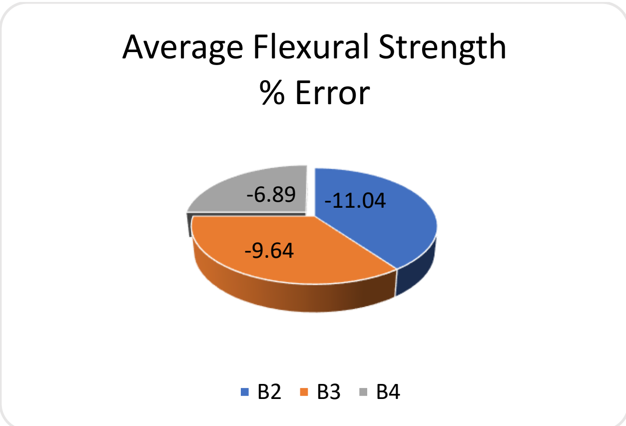

Fig. 21. Flexural Strength Deviation (RC1)

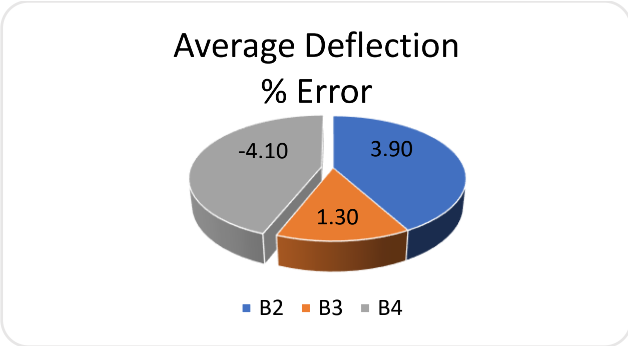

Fig. 22. Flexural Strength Deviation (RC2)

7. Deflection

During the testing of the beams, the deflection at regular intervals was recorded and is plotted in Fig. 23 to Fig. 26 for all four batches. It may be observed that the deflection pattern of the specimen within the batch is similar except for minor deviation in the maximum sustained load and deflection. The deflection pattern of the specimens across the batches also agreed well with each other. The average maximum deflection of conventional concrete was recorded as equal to 2 mm. The same increased by about 4% due to the induction of recycled aggregates and about 2% more in beams with the RC1 group of aggregates and fly ash. But it reduced by about 4% with the RC2 group of aggregates and fly ash. It is because of the reason that the fly ash provides better interlocking of the concrete ingredients thus making it capable of resisting more deflection. In all cases the average deflection of the beams was well below the permissible limits of ACI-318. This shows that combination of recycled aggregates and fly ash has potential of good control of deflection in beam particularly when the parent strength of the recycled aggregates is high. Additionally, it was also observed that the recorded deflection of the proposed concrete beams was lower compared to the deflection reported for recycled aggregate concrete beams in reference [35]. This proves the better strength of the beams and better control against the deflection under the load.

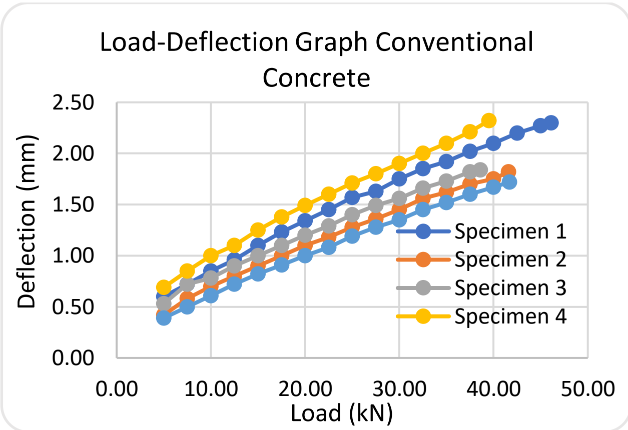

Fig. 23. Load-Deflection (B1)

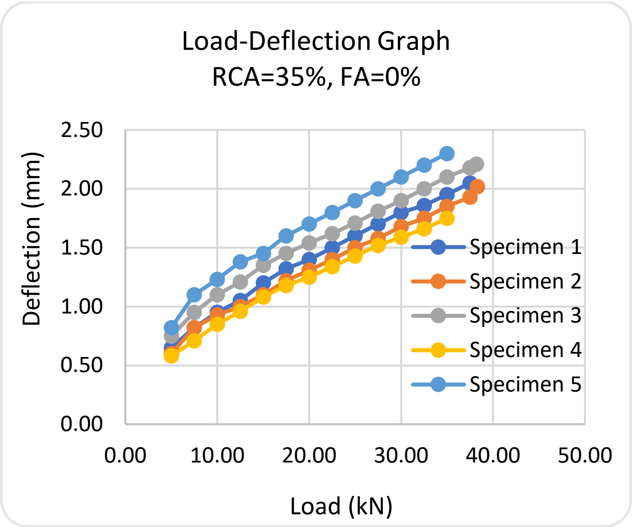

Fig. 24. Load-Deflection (B2)

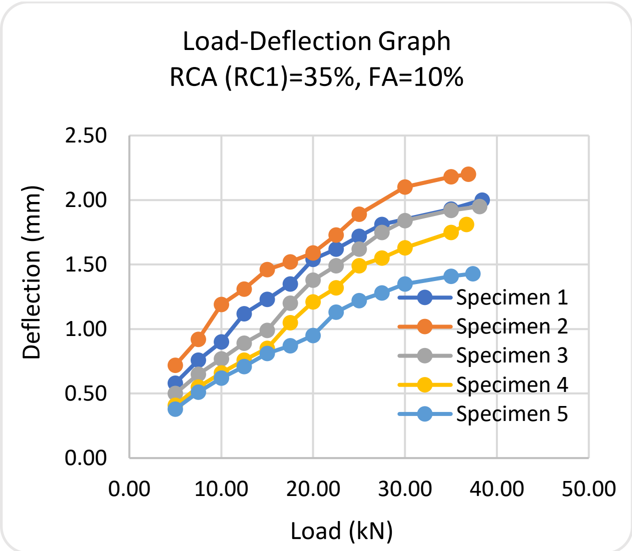

Fig. 25. Load-Deflection (B3)

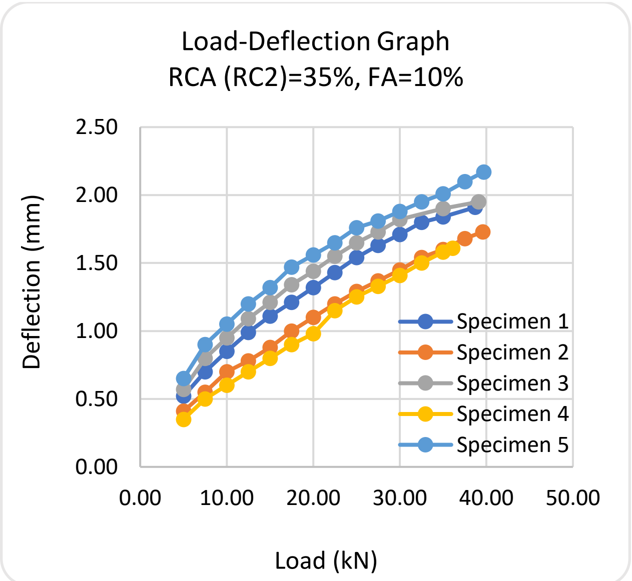

Fig. 26. Load-Deflection (B4)

8. Conclusion

The laboratory investigations of green concrete blended with recycled aggregates from demolished waste and fly ash followings are concluded.

1) The specific gravity, density, and unit weight of recycled aggregates is less compared to those of conventional aggregates. Whereas, water absorption, fineness modulus, impact value, crushing value, abrasion and soundness are higher due to pores and old mortar attached to the aggregates.

2) A comparison of the results of 55 cylinders with control concrete reveals that 35% dosage of recycled aggregates along with 65% conventional aggregates is optimum as the residual strength of concrete at this replacement level is highest (85%).

3) Optimization of the dosage of fly ash from the compressive strength results revealed that 10% replacement of cement with fly ash is optimum, as at this replacement level residual strength of concrete was 92%.

4) Analysis of the parent strength of demolished concrete showed that old concrete with higher designed strength gives better results than lower designed strength. Hence column concrete with a design ratio of 1:1.5:3 showed better results than concrete having a mix ratio of 1:2:4.

5) The flexural strength of 28-cured beam specimens showed an 11% reduction due to the presence of recycled aggregates. But it improved due to the addition of fly ash. The maximum reduction in flexural strength was recorded at 7% with higher-strength recycled aggregates. This shows that fly ash has the potential to act as a cement replacement and additive to improve the flexural strength of the concrete.

6) The load-deflection behavior of concrete beams with recycled aggregate was in good agreement with those of conventional concrete. The presence of fly ash reduced the deflection to some extent than the deflection of specimens without fly ash.

Therefore, it is concluded that both old concrete and fly ash have good potential to act as coarse aggregate and cement replacements. However, deviation of basic properties particularly water absorption should be considered while designing the mix to make concrete workable. The use of two waste materials in new concrete will not only lessen the burden on conventional resources but also help in protecting the environment. The waste materials will also prove as the indigenous alternative to conventional concrete ingredients.

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