W/C REDUCTION FOR FLEXURAL STRENGTHENING OF R.C BEAMS HAVING PLASTIC AGGREGATE

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ABSTRACT

Due to the greater availability and low biodegradability plastic waste became a great concern for the researchers worldwide, because this waste is one of the main environmental issues. Nowadays harmful industrial waste can be helpful in place of conventional aggregate in concrete mix, which in turn will also save natural resources. A similar effort has been made in this research study for making concrete having replaced percentage of plastic aggregate along with plasticizer and reduced water cement ratio. Total of fifty-seven concrete cylinders and six beams were cast, and after curing period, these were tested for compression and flexural strength respectively. Compression strength decreases by increasing the percentages of plastic aggregates while reducing the w/c, the compression strength increases. The strength of beams in flexure increases by 57% through reduction of W/C from 0.68 (normal concrete/fc'=3000psi) to 0.3, and with further replacement of 40% plastic aggregate the increase in strength as compared to the normal concrete was still 3%.

KEYWORDS

Plastic Aggregate (PA), Flexural Strength (FS), Compressive Strength (CS), Water Cement Ratio (W/C), Superplasticizer (SP)

INTRODUCTION

A significant increase for aggregate demand is just because of increase in population day by day. The changed life style of human being adds much solid waste to the environment. We can reduce some of the problems caused by these solid waste through productive use of the waste and thus we can benefit our world in the form of reduced environmental pollution, saving and sustaining natural resources and recycling energy products. Nowadays many research works are conducted to determine the possible disposal of plastic waste to be replaced in place of mineral aggregates, especially in situations where the main concern is dead weight reduction rather than strength.

Many research works have been conducted to modify the concrete mix by replacing some of the components of concrete such as coarse and fine aggregates and cement with different industrial and solid waste materials. In concrete, these materials are beneficial to be added either as a part of mineral aggregate or as a partly replacement of fine aggregate. Due to heavy weight of concrete, it can be used in skyscrapers because use of plastic aggregate will make the concrete light and then eventually the entire structure [1].

Plastic aggregates which are non-biodegradable and can be successfully replaced with mineral aggregates in concrete mix, which reduce the bulk density of concrete and it light weight. By replacing 10% to 50% of mineral aggregates with recycled plastic aggregates, bulk density decreases in the range of 2.5% to 13% as compare to the concrete having 0% of plastic aggregates. The replacement of 10% to 50% of recycled plastic aggregates with mineral coarse aggregates in

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concrete mix reduces compression strength of concrete in the range of 34% to 67% compare to normal concrete [2].

Another research work was carried out by replacing 20% of plastic aggregates with the mineral coarse aggregate. After testing the concrete cylinders, it was concluded that the CS and split-tensile strength of concrete mix were reduced than that of concrete having only mineral coarse aggregates. Hence, it is advised that concrete having recycled PA should be used in non-structural applications of civil engineering where the strength requirement is up to 25 Mpa (3626 Psi). Eventually, this will reduce the cost of non-structural concrete [3].

Kou et al. concluded from their research work that increasing the plastic aggregates percentage, reduction occurs in the CS of concrete mix as well as in the split tensile strength. On the other hand, the poisson's ratio increased and modulus of elasticity decreased due to which ductility increased and chloride ion & drying shrinkage were also enhanced [4].

Saikia et al. in 2012 demonstrated that several strength related properties of the concrete having plastic aggregates will decrease, regardless of the percentages and type of PA. The reason behind the decrease in the concrete strength is the weak bonding between binding material and PA. By replacing 20% of mineral course aggregates with PA in concrete, CS of the resulting concrete was reduced up to 72% than that of control specimen. And by replacing 50% of fine aggregate by volume with the fine particles of plastic, the compressive strength reduction was reported up to 16%. It is concluded from the above results that either replacing course aggregates or replacing fine aggregates in the concrete with PA, the CS will reduce. The difference in the behaviour of concrete in each case (replacing fine or course aggregates) is due to the difference in shape, size and workability of concrete mixture [5].

The decrease in the CS of concrete mixture is directly proportional to the addition of PA in concrete mix. Also by increasing the PA in the concrete mix, the modulus of elasticity decreases but the ductility of concrete increases by increasing plastic aggregates compare to the normal concrete. It is cleared that concrete containing plastic aggregates can be used in stone curb and park benches etc. where they are not exposed to heavy loads [6].

In 2016 Colangelo et al. reported that the CS as well as concrete density decreases by replacing mineral aggregates with plastic aggregates in concrete. The reduction in the concrete density indicates that PA has lower density than mineral aggregates. Another reason for reduction in concrete density is the air trapped during mixing of plastic aggregates [7].

In 2016 another research work was carried out by Gu et al. and concluded that FS, split tensile strength, elastic modulus and CS decreases with the increase in PA in concrete mix. Moreover, the above strength related properties decreases more gently for concrete containing non-uniform shaped recycled plastic aggregates compare to concrete containing uniformly shaped plastic aggregates. By adding plastic aggregates in concrete, ductility improves but result in lower peak stress as compared to traditional concrete [8].

In 2005 a research work was carried out and demonstrated that 2–6% reduction in weight is possible through the addition of plastic aggregate as related to that of ordinary weight concrete. Although, the reduction of strength in compression was about 33% as compared to that of conventional concrete [9]. The same results were obtained from the experimental investigation of Batayeneh et al. (2007) in which the decrease of strength in compression was directly proportional to the increase in the addition of plastic aggregate [10].

Another research work investigated the physical, chemical and mechanical behaviour of concrete mix incorporated with plastic aggregate. Their findings showed that there would be no substantial alteration in the concrete mechanical behaviour if we incorporate plastic aggregate in quantity less than 10% by volume in the concrete matrix [11].

In one of the research polyethylene, terephthalate fibers were used to determine the concrete mechanical properties; with the main concern to measure the influence of various dimensions and geometries on the concrete mechanical properties. Marthong's conclusions declare that the workability effected by a very small amount by changing the fibers geometry [12].

In another research work researcher replaced various percentages of sand in concrete mix with the waste plastic. Concrete was investigated in hardened state as well as in wet state with the main concern on the toughness index test. The research declared that with replacement of sand through waste plastic the generation of micro cracks can be arrested because a fabric form shape is provided by plastic waste to concrete mixture [13].

The basic assumption, which is supported by experimental data reveals that the strength of hardened form of cement paste is the main agent that controls the structural concrete strength, which in turn is in the control of W/C and is defined as the quantity of water present in the fresh concrete mixture to the quantity of cement. Thus, it is clear that the relation between water cement ratios versus concrete strength is the base for modern concrete technology.

Concrete produced with 10%, 20%, 30%, 40% and 50% plastic aggregate. The plastic aggregate addition up to 20% in place of mineral aggregate will still give strength value with in permissible range. Beyond 20%, replacement of mineral aggregate with that of PA will reduce the density of concrete mix [14].

The concrete mechanical properties, such as CS and FS having polymer based on recycled Polyethylene terephthalate, and the results showed that energy saving along with reduction in material cost is possible [15].

Plastic aggregate is lightweight aggregate and incorporation of plastic aggregate in concrete mixture will give much better results than the addition of other naturally used lightweight aggregate. The poor mechanical properties in most of the studies are because of reduced bond strength between cement paste and plastic coarse aggregate [16].

Thus, the above discussions lead to study and promote the replacement of higher percentages of PA replacement with mineral coarse aggregate in concrete mix. This research work has been conducted to discover the concrete CS and FS of concrete containing higher percentages of PA with reduced w/c.

SELECTION AND LABORATORY TESTING OF MATERIALS

The test conducted on all the material used such as fine aggregates, coarse aggregate and cement had all the values within allowable limit according to the ASTM codes.

Plastic aggregates were made by crushing plastic waste i.e. PET (Polyethylene Terephthalate) bottles, plastic shopping bags, straws, plastic packing and other plastic items. These Plastic coarse aggregates are shown in Figure 1.

Fig. 1 – Curing stage of concrete cylinder

Additives are usually added to modern concert, which may be added either in chemical form or in mineral form. To improve workability of concrete mix we usually add superplasticizer and plasticizers, which are high range water reducers and reducers respectively, and both are chemical admixtures. There will be inverse relation between the concrete strength and added water or water cement ratio when the added water is not enough in the concrete mix. Plasticizer or superplasticizer will be required for greater workability when added water is too less for producing stronger concrete. Addition of 1-3% superplasticizer by weight of cement is usually sufficient as higher percentages are not advisable because it will cause excessive concrete segregation [17].

To maintain the workability of concrete mix, organic polymer blend superplasticizer (Chemrite 520 BA-S) was used. The slump test was carried out as per BS EN 12350 (2000) standard. The advisable range of superplasticizer is 0.6-3% per unit weight of cement for Chemrite 520 BA-S. Three trials were performed for each type of concrete to define the percentage of superplasticizer for the given W/C. Thus, superplasticizer of 0.75% per unit weight of cement was defined to be added for a W/C of 0.5, 1% super plasticizer per unit weight of binder (cement) for a W/C of 0.4 and 2.5% superplasticizer per unit weight of binder for a W/C of 0.3. Table 1 shows Mix Design for Concrete Specimen.

Tab. 1- Concrete Mix Design

Ratios	Cement : Fine Aggregate : Coarse Aggregate : PA				
	W/C = 0.68	W/C = 0.56	W/C = 0.5	W/C = 0.4	W/C = 0.3
0 % PA	1:3.1:4.4:0.0	1: 2.4:3.5:0	1:2:3.2:0.0	1:1.5:2.6:0.0	1:0.9:1.9:0.0
15 % PA	×	1:2.4:3.0:0.3	×	×	×
20 % PA	×	1:2.4:2.8:0.4	×	×	×
25 % PA	×	×	1:2:2.4:0.4	1:1.5:2:0.3	1:0.9:1.4:0.3
30 % PA	×	×	1:2:2.2:0.5	1:1.5:1.8:0.4	1:0.9:1.3:0.3
35 % PA	×	×	1:2:2:0.6	1:1.5:1.7:0.5	1:0.9:1.3:0.4
40 % PA	×	×	1:2:1.9:0.7	1:1.5:1.5:0.6	1:0.9:1.2:0.4

According to the ASTM standard C470/C470M-15 three concrete cylinders for each mix were prepared having dimensions of 1 feet height and ½ feet diameter. Total of 57 concrete cylinders were caste for different percentages of plastic aggregates having different water to cement ratios, as shown in the test matrix in Table 2.

Tab. 2- Test Matrix

Percentage of Plastic aggregates	No of Cylinders for W/C = 0.68	No of Cylinders for W/C = 0.56	No of Cylinders for W/C = 0.5	No of Cylinders for W/C = 0.4	No of Cylinders for W/C = 0.3
0% PA	3	3	3	3	3
15% PA	×	3	×	×	×
20% PA	×	3	×	×	×
25% PA	×	×	3	3	3
30% PA	×	×	3	3	3
35% PA	×	×	3	3	3
40% PA	×	×	3	3	3
Total	3	9	15	15	15
57					

According to the ASTM standard these concrete cylinders were tested through Universal Testing Machine (UTM) for compression strength after twenty-eight days of curing as shown in Figure 2 and 3 (a) and (b).

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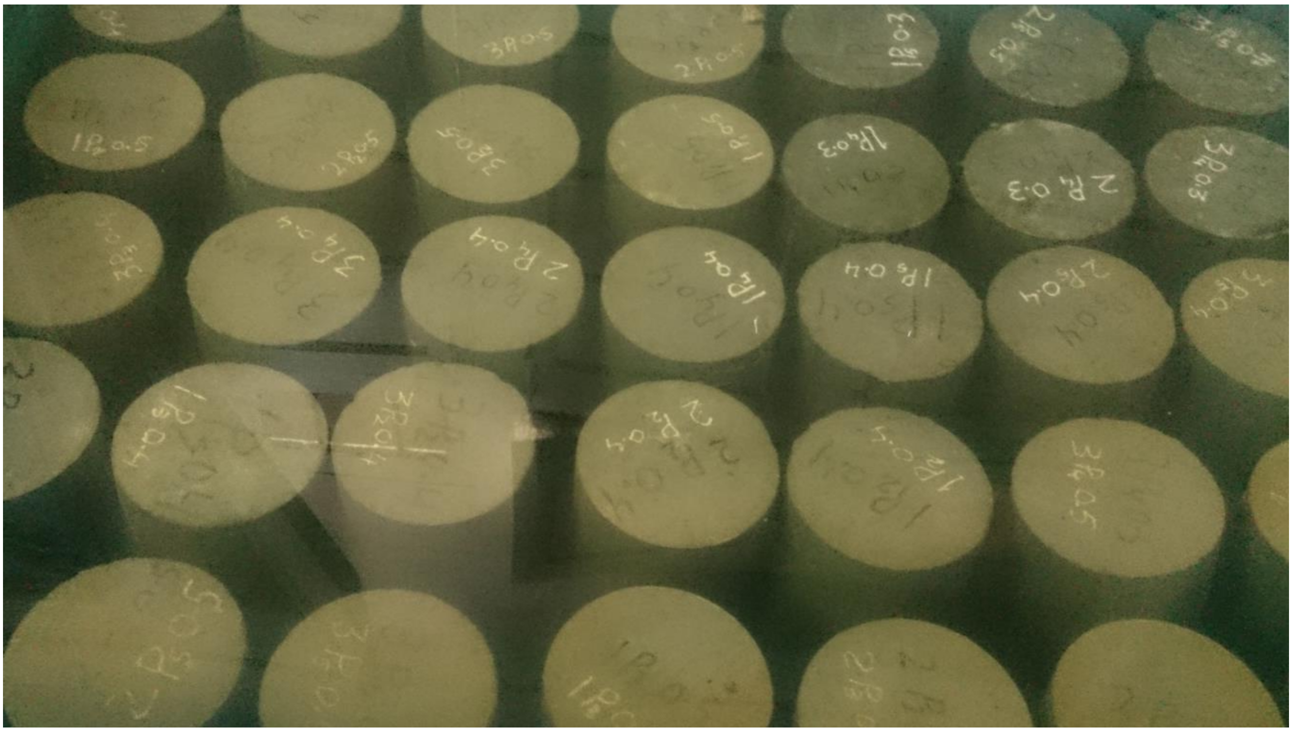

Fig. 2 – Curing stage of concrete cylinder

Fig. 3 – (a) & (b) Compressive test of concrete cylinder

The average compression strength of concrete cylinders obtained from the testing of concrete cylinders through UTM are shown in Table 3.

Tab. 3- Average CS ofcConcrete cylinders

	W/C = 0.68	W/C = 0.56	W/C = 0.5	W/C = 0.4	W/C = 0.3
Plastic Aggregate Percentage	Average CS of Concrete (Psi)	Average CS of Concrete (Psi)	Average CS of Concrete (Psi)	Average CS of Concrete (Psi)	Average CS of Concrete (Psi)
0	3008	3609	3936	5048	6712
15	×	3254	×	×	×
20	×	2983	×	×	×
25	×	×	2918	3432	3674
30	×	×	2798	3136	3555
35	×	×	2637	2996	3037
40	×	×	2466	2878	2953

Based on compression test results six beams were designed and cast for flexural testing with clear span equals six feet and cross sectional area of 6x9 in^2. Among them two were controlled beams (fc'=3000psi and provided with flexural reinforcement based on minimum steel reinforcement as per the ACI-318-08). Two beams with w/c of 0.3 containing PA of 0% while the last two beams had a w/c of 0.3 containing PA of 40% with compression strength (fc') of 6700psi which was obtained from compression test conducted on concrete cylinders as per ASTM standard C470/C470M-15. The beams were tested for flexural strength as per ASTM C78/78M-10 using the third point loading criteria, as shown in Figure 4.

Fig. 4 – Third point loading

The load application rate was 0.2 ton/sec by the loading cells having a total capacity of 100 ton. The data is tabulated in Table 4 and Figure 5, 6 and 7 shows flexural strength results.

Tab. 4- Flexural strength testing results

	Avg: Ultimate load (kips)	Avg: Deflection (mm)
Normal concrete (fc'= 3000 psi)	10.40	25.16
0 % Plastic Aggregate, W/C=0.3	16.40	38.23
40 % Plastic Aggregate, W/C=0.3	10.73	53.08

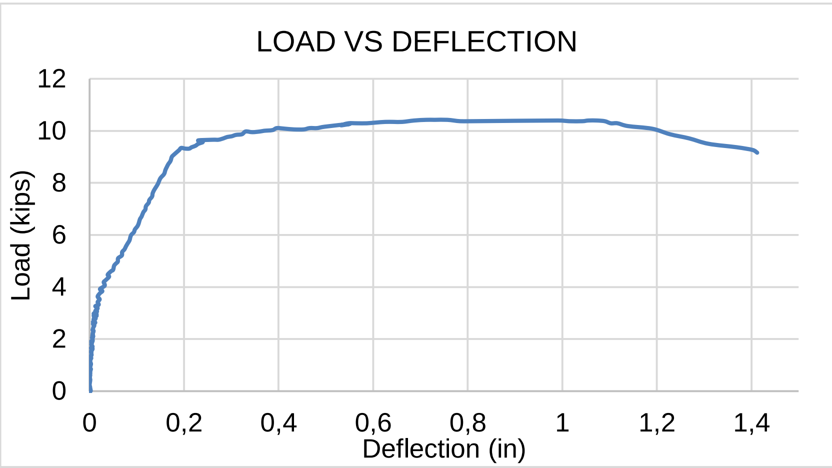

Fig. 5 – Average load vs. deflection curves for beams having W/C=0.68, PCA=0%

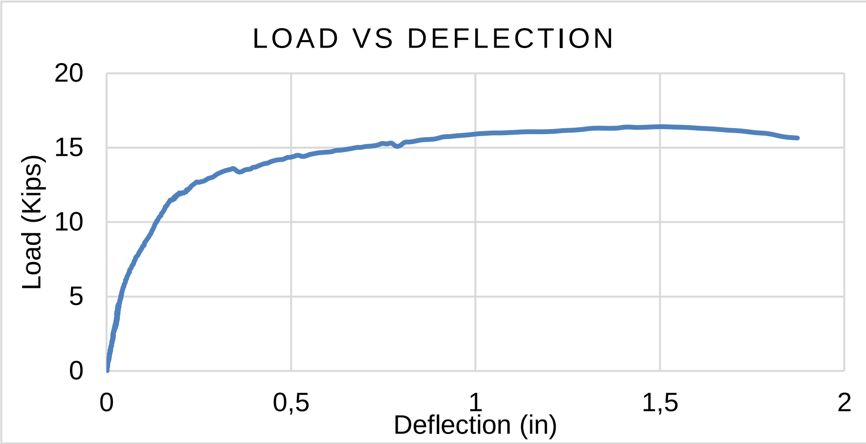

Fig. 6 – Average load vs. deflection curves for beams having W/C=0.3, PCA=0%

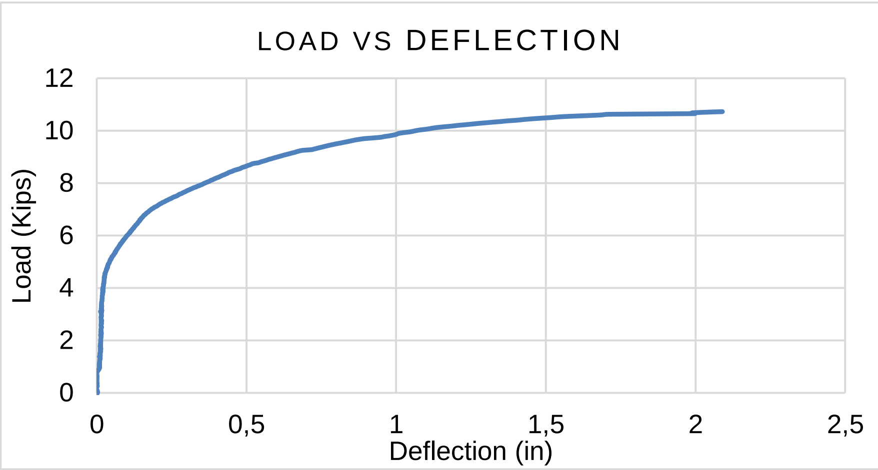

Fig. 7 – Average load vs. deflection curves for beams having W/C=0.3, PCA=40%

The specimens with the plastic coarse aggregate replacement of 40% took more load than the specimens having W/C of 0.68, with the increase in flexural strength equals 3% only. Although the increase in flexural strength of specimens with 0% plastic aggregate and W/C 0.3 was 57% as related to that of traditional concrete.

Since all the specimens were designed for maximum shear, therefore no shear cracks were observed. All the cracks observed were purely flexural cracks as shown below in Figure 8.

Fig. 8 – Crack pattern in 40% PCA specimen

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CONCLUSION

From this research work, following decisions were made.

- The reduction in slump value because of plastic coarse aggregate addition best suits this concrete mix for situation where we need lower workability.
- By replacing 40% plastic aggregates with natural coarse aggregates, weight of concrete can be reduced up to 25-30% as compared to normal concrete.
- Higher percentages of plastic aggregates can be utilized in concrete mixture by reducing their w/c with the help of superplasticizers.
- As increasing the percentage of plastic aggregates in concrete from 0% replacement to 40% replacement of natural coarse aggregates, reduction in the CS of concrete occurs. The reduction in the CS of concrete having PA is due to weak bond between PA and the cement paste, which disturb the concrete interlocking arrangement.
- However, by reducing the w/c by using superplasticizers, the CS of concrete having PA increases.
- Concrete beam cast using PA as a replacement of mineral coarse aggregates increases ductility.
- The increase in ductility as a result of plastic aggregate addition can help to stop the cracks that can be generated during concrete mechanical failure.
- The strength of beams in flexural increases to 57% by lowering of W/C from 0.68 (normal concrete) to W/C of 0.3.
- Furthermore, by adding of plastic course aggregate of 40% to the mix having the same W/C of 0.3, FS decreases, and the obtained average value of flexural strength is only 3% more than that of normal concrete mix having W/C equal to 0.68.
- Thus, increasing the percentages of plastic aggregate with reduced W/C gives equal or even better performance in flexural strength than conventional concrete and thus can be used where dead load reduction is of prime concern.

CONFLICT OF INTEREST

The authors of this research paper, whose names are listed on title page, certify that they have developed this research entirely on the basis of their personal efforts made under the sincere guidance of the supervisor. The authors also certify that they have carried out this research work as final year project for the fulfilment of their graduate degree course through self-financing.

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