ASSESSING THE FLEXURAL STRENGTH OF A BEAM USING WASTE PLASTIC AS A PARTIAL SUBSTITUTE FOR COARSE AGGREGATE

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Abstract- In order to promote resource conservation, recycling plastic waste is crucial as it is durable and does not decompose. Nowadays, the concrete industry worldwide is constantly seeking to develop effective materials that are lightweight, cost-effective, and eco-friendly. To achieve the desired properties in concrete while reducing its negative effects on the environment, plastic waste can be utilized as a partial substitute for coarse aggregate. Previous research has suggested that a 10-20% replacement of coarse aggregate with plastic aggregate is ideal. This study comprised of two phases. During initial phase, concrete cylinders were examined, each containing with different proportion of plastic aggregate as a partial replacement, and favorable outcome were achieved with 20% replacement. In the second phase, three Reinforced Concrete (RC) beams were built, with two beams using 20% replacement of coarse aggregate with plastic aggregate and the third as a control specimen for comparison purposes. All beams were designed according to the ACL code and tested under third-point loading in accordance with ASTM C78/C78M to investigate their flexural behavior at midspan. The beams with partial plastic aggregate replacement exhibited almost identical flexural behavior while reducing their self-weight by 14%.

Keywords- Flexure Strength, Coarse Aggregate, Waste Plastic, concrete.

1 Introduction

Concrete, being highly versatile, is widely utilized in various forms of construction and is considered one of the most essential building materials after water [1].During the 1960s, there was a shift towards utilizing reinforced cement concrete instead of girders, steel decking, and steel columns for both structural and non-structural components. [2]–[4].The aggregate, consist of fine and coarse components, constitute 70% of concrete mix [3]. The presence of this particular aggregate greatly affects the weight of the concrete itself. By employing low-density aggregates, it becomes possible to decrease the overall dead load of a structure, leading to lighter burdens on supporting elements. Consequently, this can result in a reduced seismic reactive mass.

In recent years, researchers have been dedicated to identifying aggregates with low specific gravity for concrete. They have conducted tests using various materials and achieved satisfactory outcomes, such as reduced self-weight aggregates or minimum loss of strength. As a result, different types of lightweight aggregates, including expanded clay aggregate, volcanic pumice, fly ash, rice husk, and rubberized aggregate, etc. have been introduced to the concrete industry.

Numerous studies have been conducted to assess the properties of lightweight aggregates both as standalone materials and when incorporated into concrete. The effect on properties of hardened and fresh concrete having plastic aggregate is already discussed by several researchers [5]. The Researchers also discussed the effect of level of use of fine PA in place of CA on workability [6], thermal conductivity [7], abrasion resistance [8], shrinkage [9], permeability [10], fire behaviour [11] and absorption [12]. Even some researchers reported decrease in slump of fresh concrete [13]. Polymeric material found in domestic and industrial waste, primarily rubber and plastic, have both economic and environmental impacts. These materials usually either disposed of in landfill or burned in dumps. This addresses the environmental impact, while their utilization in construction or industry addresses the economic impact.

In Pakistan 30 million tons of solid waste is generated per year, in which 9% is plastics.9 million tonnes of plastic are thrown into ocean annually [14]. The consumption of plastic materials has witnessed a significant surge, rising from around two million tons in the 1950s to nearly four hundred and forty million tons in 2015 [15]. The excessive accumulation of plastic waste poses environmental pollution threat and indirectly contributes to issues like flooding by obstructing drainage systems, as observed in Karachi, Pakistan in 2017 (Amar Guiro, September 2017). By incorporating plastic waste as a substitute for coarse aggregate in recycling practices, not only can the detrimental effects of plastic waste be mitigated, but also the overall weight of structures can be reduced. This is facilitated by the availability and low or less density of plastic, which allows it in serving as a alternative to traditional coarse aggregate.

In recent years, construction industry has embraced recycled concrete and waste plastic aggregates to study their tension and compression properties for effective utilization. Plastic aggregates from various sources such as plastic bottles ,wrapper, shopping bags and recycled rubber from tires have been successfully as partial replacement for coarse aggregates in concrete. These efforts have yielded satisfactory outcomes [16].

In this paper, three beams specimens were made for experimentation purposes. One beam was used as a specimen for comparative analysis, while the remaining beams were made with a substitution of 20% with plastic aggregates. The design of all beams adhered to the standards outlined in the ACI code and underwent testing using the third-point loading method as outlined in ASTM C78/C78M. [17-20]. Flexure strength, ductility, self-weight, and damage pattern of both types were compared.

The significance of this research lies in exploring the potential of utilizing waste plastic aggregates as a partial replacement for traditional coarse aggregates in concrete construction. This approach addresses both economic and environmental concerns by recycling plastic waste and reducing the overall weight of structures. The objective of the study is to investigate the mechanical properties, such as flexural strength, ductility, and self-weight, of concrete beams with 20% plastic aggregate substitution. By comparing these properties with the control specimens, the study aims to determine the feasibility and effectiveness of using waste plastic aggregates in concrete mix designs, contributing to sustainable and eco-friendly construction practices.

2 Experimental Procedures

Due to limited understanding of the properties of the recycled plastic aggregate taken from FF Steels (PVT.) Ltd in Islamabad, a thorough investigation was necessary to ascertain the material's various qualities essential for concrete mix design. The plastic aggregate ranged in size from 12mm to 14mm. The grading of the coarse aggregate was adjusted to replace the natural coarse aggregate with plastic aggregate. Additional properties of the plastic aggregate were documented and are presented in Table 1. Considering the desired compressive strength of 3ksi, the targeted slump range of 1 to 2 inches, and a w/c of 0.56, the following ratios have been estimated in accordance with the ACI code, considering the given qualities and specifications.

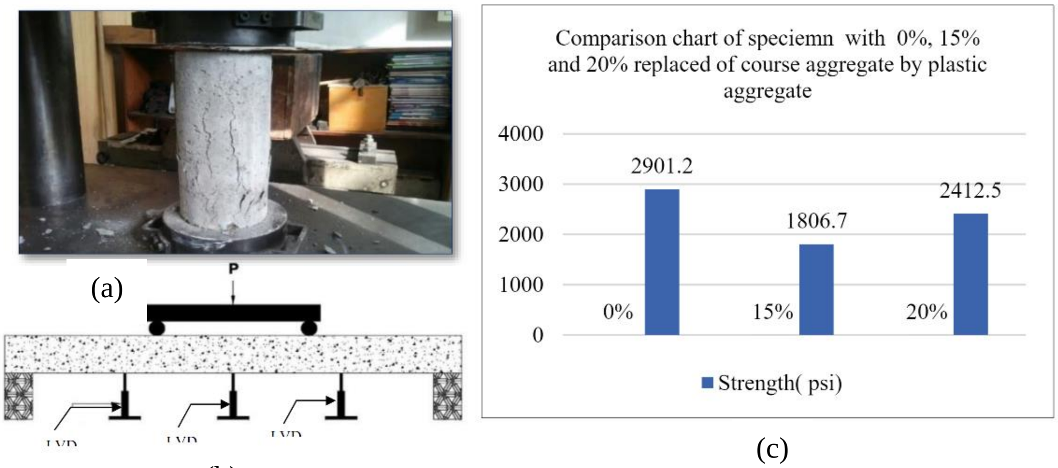
Table 1 Properties of Materials

Material	Size (inch)	Specific gravity
Courser Aggregate	1 (maximum)	2.67
Fine Aggregate	3 FM	2.6
Plastic Aggregate	0.5	0.85

Table 1 Estimated values of material ratio

% Of Plastic aggregate	Cement (lb./yd3)	Coarse Aggregate (lb/yd3)	Fine Aggregate (lb/yd3)	Plastic Aggregate (lb/yd3)	w/c
0	517.24	1240.20	1821.70	0.0	0.56
15	517.24	1240.20	1548.40	141	0.56
20	517.24	1240.20	1457.30	188	0.56

Due to the limitations in strength and workability, it is not feasible to entirely replace the coarse aggregate with plastic aggregate. Research findings suggest that replacing 15 to 22 percent of the coarse aggregate with plastic aggregate yields favorable outcomes [19]. In this particular study, the focus was on replacing 15 and 20 percent of the coarse aggregate. In this research study, a total of nine cylinders were prepared and subjected to testing in accordance with ASTM specifications. The obtained results are outlined as follows:



(b)

Figure 1 (a) Testing of Concrete cylinder (b) Three-point loading(c) Compressive strength of cylinder

Based on the data presented in the figure, the observed trend of decreasing compressive strength with a 15% plastic aggregate replacement and increasing compressive strength with a 20% replacement can be attributed to the complex interactions between the plastic aggregate and the other constituents of the concrete mix. At a 15% replacement level, the introduction of plastic aggregates might have caused a disruption in the overall matrix, leading to a less efficient packing arrangement and weaker bond formation between the aggregates and the cement paste. Consequently, this could have resulted in a slight decrease in compressive strength. However, at a 20% replacement level, the plastic aggregates could have facilitated better particle distribution and enhanced packing, leading to improved load transfer and interlocking within the mix. This optimized arrangement may have positively influenced the overall compressive strength, resulting in a higher value. The specific characteristics of the plastic aggregates and their interactions with the other concrete components play crucial roles in influencing this trend, making further research essential to comprehend the underlying mechanisms in detail.

1.1 Specifications of Beam Specimens

For research purposes, three beams were built, with one as control specimen(without plastic aggregate) and other two incorporating 20% plastic aggregate. All three beams were prepared using same mix proportion as the concrete cylinders. The beam specimen was 7ft long, had cross section of 6" × 9" as shown in the figure 3b.and were reinforced for shear in accordance with ACI code.

Figure 2: Testing of Beam specimen

1.2 Experimental Testing of Beam Specimens

At the material testing laboratory of HITEC UNIVERSITY in Taxila, Pakistan, the three specimens underwent three-point loading tests in accordance with the ASTM C78/C78M-10 standard.

The specimens, configured as beams with a 6-foot clear span, were positioned within the test setup. Strain gauges were affixed at the location of maximum bending to monitor deflections. All specimens underwent testing using the loading criteria specified in section 2.5, employing a 0.33 factor. The load was incrementally applied at a rate of 0.2 ton per second.

In order to measure deflection, three Linear Variable Differential Transformers (LVDTS) or At the bottom of the beam, gauges were installed to measure and monitor the load and deflection. The collected data was then analyzed to assess the flexural capacity of the specimens. This information is illustrated below.

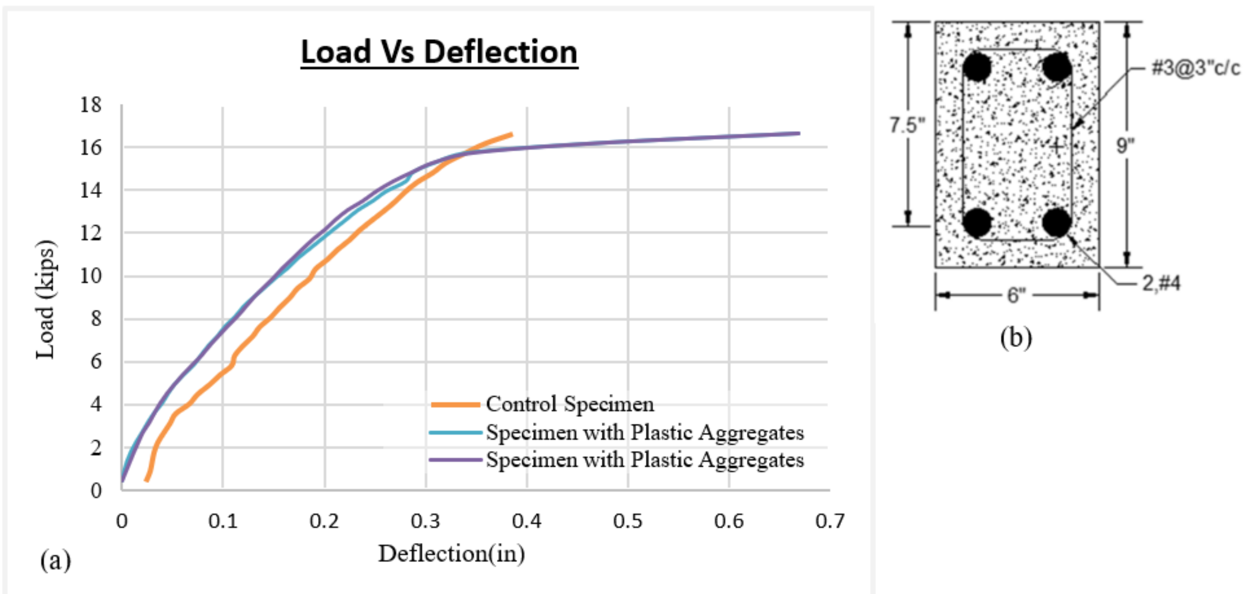


Figure 2: (a) Load vs Deflection Chart of Beam specimen (b) Cross section of beam

2 Results and Discussion

Upon comparing the lightweight specimens (with partial replacement) with the specimen for comparative analysis, it was noted that the flexural capacity of the lightweight specimens was on par with that of the control specimen.

- In contrast to the control specimen, the beams exhibited a heightened level of ductile failure.
- The replacement of 20% plastic coarse aggregate in reinforced concrete (RC) beams did not affect their flexural capacity when compared to the control specimen. However, there was a noteworthy reduction of 18 to 20% in the self-weight of the beams.
- Cracks on the tension face of the beams with partial replacement of coarse aggregate were uniformly distributed. This suggests that the presence of plastic aggregate did not lead to concentrated or localized cracking. Instead, the cracks were evenly distributed, indicating a more uniform and balanced distribution of tensile stresses within the beam. This signifies that the beams with partial replacement maintained structural integrity and exhibited improved resistance to cracking. Such uniform crack distribution is beneficial for the overall performance and durability of the beams.
- Prior to the development of flexural cracks, the beams exhibited resistance against shear forces and did not display any signs of shear cracks. This indicates the structural integrity of the beams in terms of their ability to withstand

shear stresses without exhibiting any visible indications of shear failure. The absence of shear cracks before the occurrence of flexural cracks highlights the strength and stability of the beams under applied loads.

- Based on the findings of this research and previous recommendations, it can be concluded that the practical application of plastic aggregate as a partial replacement for coarse aggregate is feasible, with an optimum replacement level of up to 20%, is feasible in the concrete. However, it is advisable to conduct further studies exploring the effects of different water-to-cement ratios (w/c) and higher percentages of plastic aggregates. These additional investigations will provide valuable insights into the behavior and performance of concrete when subjected to varying conditions of w/c and increased levels of plastic aggregate replacement.

3 Conclusions

The study demonstrated that the use of plastic aggregate as a partial replacement for coarse aggregate, up to 20%, in reinforced concrete beams resulted in beams with comparable flexural capacity to the control specimens. The lightweight beams exhibited a higher level of ductile failure and a noteworthy reduction in self-weight, showcasing their potential benefits for lightweight construction. Moreover, the presence of plastic aggregate led to uniformly distributed cracks on the tension face, indicating improved resistance to localized cracking and enhanced structural integrity. The beams also demonstrated resistance against shear forces without displaying shear cracks before the development of flexural cracks. While the practical application of plastic aggregate in concrete is feasible, further research investigating different water-to-cement ratios and higher percentages of plastic aggregate replacement is recommended to gain a deeper understanding of its behavior under varying conditions.

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