Recycling of Waste Plastic into Fine-Grained Concrete Without Strength Reduction

M Chekanovich, S Romanenko and Ya Andriievksa
Kherson State Agrarian and Economic University, 23 Stritenska st., Kherson 73006, Ukraine
E-mail: mchekanovych@gmail.com

Abstract. The problem of recycling plastic waste is quite acute both in Ukraine and for most countries of the world. The use of plastic processing products can be considered an urgent problem of society from the point of view of environmental protection and environmental safety. Today, developments are underway in the field of using polymers in one of the largest sectors of production – the construction industry. In recent years, the scientific community has been actively studying the issue of using plastic waste in the manufacture of reinforced concrete structures, that is, partial replacement of the filler with plastic particles. At the same time, in the short term, sufficient resources of plastic waste will be provided, which will come in value for collection and recycling. The use of plastic in concrete production technology will not only reduce the negative impact of waste on the environment, but also develop concrete of more sustainable quality and lower cost. The aim of the study is determining the amount of plastic waste that can be utilized through introducing it into concrete mix without reducing the strength of the concrete. Here we have considered the issue of the impact of the degree of plastic grinding on concrete strength. The research findings show that the introduction of plastic in an amount up to 3.5% of the volume of concrete as a substitute for the aggregate does not reduce its compressive or flexural strength.

1. Introduction
Taking into account the particular importance of the problem of environmental pollution [1] with plastic waste and the strict need to find ways to solve it, the scientific community annually conducts research aimed at studying the issue of using plastic waste in industry, including in the technology of concrete production [1-6]. The analysis of the works revealed the ambiguity of the results in terms of assessing the effectiveness of the use of plastic waste in concrete in terms of improving its operational properties: in some cases, an increase in strength properties was observed, in others - a loss. In most cases, improvements in performance, corrosion resistance, resistance to cracking and splitting, toughness and resilience, and weight reduction were found when plastic was incorporated into concrete. A. Lisyannikov [7], Anurag V. Tiwari, Dr. Y R M Rao [8] proposes to use plastic waste in road construction. In the work of Albano C, Camacho N, Hernández M, Matheus A, Gutiérrez A. [9] studying the relationship between the replacement of sand with plastic parts of irregular shape and water-cement ratio, they found that plastic particles act as defects in the internal structure of concrete, and when using large of plastic particles, the formation of pores and voids is observed in large quantities compared to smaller particles.
A review of scientific papers illustrates the many variables associated with the use of plastic as an aggregate substitute and demonstrates the key finding that as the percentage of aggregate replacement increases, the compressive strength of concrete decreases. Therefore, the key task is to minimize the loss of strength, creating a lighter material.

The aim of research is a literature review, analysis of the results of experimental studies aimed at developing a technology for the manufacture of concretes for various purposes using plastic waste and identifying the effect of the additive on the indicators of concrete properties, determining the effectiveness of its use.

Research objectives: to develop a method for recycling plastic in the form of a fine fraction for the manufacture of concrete mixture; to experimentally investigate the features of work and the nature of destruction of concrete sample beams with the addition of particles of crushed plastic and compare them with reference samples; to determine the characteristics of compressive and tensile strength in fine-grained concrete; to analyze the results obtained after experimental studies.

2. Materials and Methods

For the manufacture of the concrete mixture, Portland cement of the M500 brand, quartz sand with a fineness modulus of $M_{cr} = 2.5$ and crushed plastic with a fraction of 5 mm and 2.5 mm with a density of $\rho_p = 92 \text{ kg/m}^3$ from recycled material of plastic bottle caps were used as a binder, see Figures 1, 2.

Figure 1. Granulometric composition of plastic.

Figure 2. Granulometric composition of plastic with a fraction of 5 mm with a fraction of 2.5 mm.
The materials used to make the concrete meet the requirements of the standards for these materials. Before starting work, all materials were tested to determine their quality indicators in accordance with the standards [10, 11]. The materials were dosed by weight with an error of not more than 1.0% and weighed on an electronic tabletop mechanical balance. The sand was dried, sieved through sieves with a hole of Ø5 mm. The suitability of water for mixing concrete mixture was determined according to DSTU B.2.7-273: 2011, EN 1008 [12].

To determine the characteristics of concrete, standard samples were made - cubes and held up to the test for 28 days. The samples were stored under normal conditions at a temperature of 18-20 °C with a relative humidity of 90%. Before testing, the samples were weighed to determine their average density according to [13]. Comparisons were made between the density of the plastic-added samples and the reference samples. To determine the physical and mechanical characteristics of concrete, four series of beams were made with the addition of crushed plastic with a fraction of 2.5 mm and 5 mm. Shredded plastic of 5, 10, 15 and 40 grams, respectively, was added to the bar samples. In detail, the number of series of samples, their composition, the content of crushed plastic of the above fractions are presented in Table 1.

Table 1. Program and scope of experimental research.

| Sample type, mm | Sample series | The amount of added shredded plastic per sample, g |
|----------------|---------------|-----------------------------------------------|
| Concrete cubes with an edge size of 100 | C-0 | 0 |
| | C-1 | 20 |
| | C-2 | 39 |
| | C-3 | 59 |
| | C-4 | 156 |
| Beams 40x40x160 | B-0 | - |
| Beam 40x40x160 with the addition of shredded plastic with a fraction of 5 mm | B-1 | 5 |
| | B-2 | 10 |
| | B-3 | 15 |
| | B-4 | 40 |
| Beam 40x40x160 with the addition of shredded plastic with a fraction of 2.5 mm | B-5 | 5 |
| | B-6 | 10 |
| | B-7 | 15 |
| | B-8 | 40 |

A general view of typical samples of beams with the addition of crushed plastic and cubes, as well as reference samples without additives, are shown in Fig. 3.

Figure 3. General view of representative samples of concrete beams and cubes before testing.
To determine the strength of concrete, experimental compression tests of control concrete cubes 100x100x100 mm were carried out. Concrete prisms 40x40x160 mm were experimentally tested first for tensile fracture, and then the resulting halves of the beams were inserted into special metal plates and tested for compression to determine the strength of concrete. Control samples of cubes and beams were made in specially tested metal molds. The cubes were tested on a P-50 hydraulic press in laboratory conditions according to the current methods [14], and the bending tests of the beams were carried out using the P-5 machine. In this case, the halves of the beams were tested for compression on a P-10 press. When testing the samples for compression, the loads were carried out continuously at a rate within 0.6 ± 0.4 MPa/s until complete destruction. The program and scope of experimental studies are shown in Table 1. This table shows the consumption of shredded plastic from waste per sample, that is, for one sample cube or for one sample beam.

3. Results and Discussion
According to the accepted methodology for experimental research on tensile splitting of prisms, where the forces from the testing machine were applied through a metal roller to determine the bending strength of the samples - beams. The first stage of the research was the bending test of beams B-1, B-2, B-3, B-4 with the addition of plastic waste and a reference beam B-0 using a mechanical tensile testing machine R-5 (Fig. 4, 5).

![Figure 4](image1.png)

**Figure 4.** General view of bending test of beams: a- with the addition of shredded plastic 5 g; b- with the addition of shredded plastic 10 g.

![Figure 5](image2.png)

**Figure 5.** General view of bending test of beams: a- with the addition of shredded plastic 15 g; b- with the addition of shredded plastic 40 g.
The strength of concrete for beams was determined by the traditional destructive method. The results of experimental studies of strength are presented in diagrams Fig. 6, 7 depending on the amount of added shredded plastic and its fraction.

**Figure 6.** Diagram of comparison of the flexural strength of fine-grained concrete with conventional and with the addition of crushed plastic with a fraction of 5 mm for sample beams.

**Figure 7.** Diagram of comparison of the bending strength of sample beams with conventional and with the addition of ground plastic with a fraction of 2.5 mm.
The second stage of the study was the compression test of the halves of the prism samples. The tests were carried out using a P-10 press. The nature of the destruction of the samples is shown in Fig. 8, 9. The results of experimental studies of the halves of the sample beams for compression after splitting are presented in the diagrams Fig. 10, 11, 12, 13.

**Figure 8.** Compression test of halves of sample beams using metal linings.

**Figure 9.** The nature of the destruction of the halves of the sample beams when tested for compression with the addition of: a- crushed plastic – 10 g; b- crushed plastic – 40 g.
**Figure 10.** Diagram of comparing the compressive strength of concrete of halves of sample beams with ordinary and with the addition of crushed plastic weighing 5 g for beams of the B-1 series with a fraction of 5 mm and for beams of the B-5 series with a fraction of 2.5 mm.

**Figure 11.** Diagram of the comparison of the compressive strength of concrete of halves of sample beams with ordinary and with the addition of crushed plastic weighing 10 g for beam B-2 with a fraction of 5 mm and for beam B-6 with a fraction of 2.5 mm.
Figure 12. Diagram for comparing the compressive strength of concrete of halves of sample beams with conventional and with the addition of crushed plastic weighing 15 g for a series of beams B-3 with a fraction of 5 mm and for beams B-7 with a fraction of 2.5 mm.

Figure 13. Diagram of comparing the compressive strength of concrete of halves of sample beams with ordinary and with the addition of crushed plastic weighing 40 g with a fraction of 5 mm for a series of beams B-4 and for beams B-8 - with a fraction of 2.5 mm.

The third stage of the study was a compression test of cube samples using a P-50 press (Fig. 14).
Figure 14. The nature of destruction of sample cubes with nominal dimensions of 100x100x100 mm.

The breaking load was taken such that it corresponded to the maximum force that was achieved during the test. For each of the samples, the compressive strength of concrete was calculated according to DSTU B V.2.7-214: 2009. The value of the cube compressive strength of concrete is given in Table 8.

Table 2. Determination of compressive strength of cubic samples.

| №  | Sample size, mm | Sample series | Sample weight, kg | Breaking load, kN | Compressive strength of concrete, MPa |
|----|-----------------|---------------|-------------------|-------------------|-------------------------------------|
| 1  | 10,1x10,2x10,0  | C-0           | 2,27              | 4166,3            | 40,83                               |
| 2  | 10,0x10,2x10,0  | C-1           | 2,24              | 4182,65           | 40,99                               |
| 3  | 10,2x10,2x10,1  | C-2           | 2,23              | 4161,22           | 40,78                               |
| 4  | 10,0x10,1x10,0  | C-3           | 2,20              | 3616,33           | 35,44                               |
| 5  | 10,2x10,0x10,0  | C-4           | 2,14              | 2867,35           | 28,1                                |

The strength of concrete in a series of four samples was determined as the arithmetic mean of the three samples with the highest strength, and the results of determining the strength of concrete were evaluated according to DSTU B. V.2.7-224.

The compressive strength of concrete during the disposal of plastic waste in the range of 20-39 kg per 1 m³ did not decrease in the study. At the same time, the tensile strength in bending may be somewhat higher, especially in studies when using a fraction of a plastic filler of a fraction up to 5 mm. In our study, such tensile strength in bending of fine-grained concrete with plastic reached 20%. This is due to the analogy of the work of plastic filler as a fiber, which inhibits the processes of cracking in concrete.

4. Conclusions

Based on the results of experimental studies, it was found that the disposal of plastic waste in concrete warehouses is effective. In the study, the content of plastic in concrete samples in the range of 20-39 kg per 1 m³ did not reduce the compressive strength of concrete and somewhat increased the tensile strength of concrete in bending, reduced the specific gravity of concrete, and contributed to the improvement of a number of physical and mechanical characteristics of fine-grained concrete. The study has also shown the possibility of increasing the strength of concrete in bending testing,
depending on the size of the plastic particles. Further detailed targeted studies are required for a substantiated quantitative effect. The considered material with crushed plastic can be used successfully as structural concrete for manufacturing load-bearing elements of buildings and structures. Among such elements are columns, foundations, slabs.

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