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Effect of Polyethylene Terephthalate, Rubber, and Glass Based on Concrete Properties

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Abstract. Given the significance of the environmental component, the concept is to combine the disposal of solid waste with acceptable structural design by incorporating those wastes into the design. The major objective is to turn garbage materials into useful ones in structural designs, which will allow us to design a structural element while considering the environmental aspect. This project aims is to investigate the effect of adding PET flakes, rubber, and glass will affect the concrete cylinders' compressive strength, tensile strength, and resistivity. With increasing percentages of used waste materials and replacing fine and coarse aggregates (sand and gravel) in concrete, our project tackles the environmental aspect of our job. Crush tests are performed to monitor the impact of these waste materials on the concrete's compressive strength, tensile strength, and resistivity to determine the appropriate amount to be added, and compare the obtained results with each other's.

Keywords. Polyethylene terephthalate, rubber, glass, concrete

1. Introduction

Concrete that has a density lower than that of regular concrete is known as lightweight concrete. To reduce the building's load, lightweight concrete should be used for tall buildings. The weight of lightweight concrete can be arranged as needed, unlike that of regular concrete [1]. This concrete type can be classified into three groups. The first group considers the low-density concrete, which has a density of 240-800 kg/m3 and compressive strength of 0.35-6.9 MPa. The second one is the moderate-strength lightweight concrete, which has a density of 800-1440 kg/m^3 and compressive strength of 6.9-17.3 MPa. The third group is the structural lightweight concrete with a density between 1440-1900 kg/m^3, and compressive strength higher than 17.3 MPa [2].

Despite some differences between governorates and districts [3, 4], waste in Lebanon consists of 52.5% organic material, 37% recyclable waste (plastics, paper/cardboard, glass, and metals), and 11% other compositions. (figure 1)

Based on estimations achieved in 2017 [5], a person in Lebanon would produce on average between 800 grams and 1.2 kg of waste per day, related to the whole country.

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This amounts to approximately 2.04 million tons of household waste per year (Lebanon's population is estimated to be around 5,600,000 Lebanese and 2,500,000 refugees).

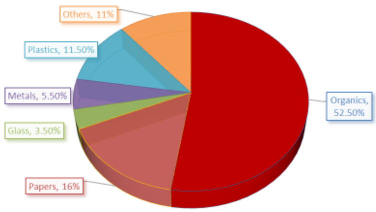


Figure 1. Waste composition in Lebanon [3, 4].

PET was pulverized so that it can be mixed with the concrete. Pulverized PET was used in concrete with three different percentages by weight of conventional fine aggregate (5%, 10%, and 15%). Four different types of concrete samples, including a control, were produced. Both flexural and compressive concrete strength of the specimens were measured after 3, 7, 14, and 28 days of curing, respectively. The specimen containing 5% PET by weight demonstrated better compressive strength than the other specimens. However, the flexural strength of the PET concrete samples was lower than that of the control concrete [6]. A recent study introduced PET in the manufacturing of lightweight concrete [7]

The rubber waste was used as coarse aggregate in concrete [8]. Referring to obtained results, and by comparing it to conventional concrete, rubberized concrete is more durable, less ductile, and has stronger fracture resistance, but has a lower compressive strength. Rubberized concrete's compressive strength may be enhanced by adding silica to it.

Several experiments were investigated on waste tire rubber concrete samples to measure both compressive and flexural strength, in addition to rupture modulus, and impact strength [9]. Four rubber proportions, as a volumetric substitution by the coarse and fine aggregate, were the key parameter studied (5%, 10%, 15%, and 20%). The results show that substituting crump-chip tier rubber for natural fine or coarse aggregates reduces mechanical properties (compressive, flexural, and splitting tensile strength), but once 20% coarse and 20% fine aggregates were replaced by rubber, respectively, impacts strength increased to 426% and 396%.

The feasibility of utilizing scrap glass from shattered containers as aggregate in mortar preparation was investigated [10]. Because of the possibility of interaction between the alkalis in the cement and the silica in the waste glass, this type of reuse is uncommon. The results indicated that the mortars are durable when employing either green or amber glass cullet and powder glass, demonstrating a substantial pozzolanic impact.

The colored waste glass was utilized in two forms: glass cullet with particle diameter between 0.125 mm and 4.00 mm as fine aggregate, and glass powders with particle diameter less than 0.125 mm as a cement substitute. A scanning electron microscope was used to analyze the microstructure of hydrated composites. It was discovered that using waste glass as a bond and aggregate replacements reduced the strength characteristics of mortar. Variations in the volumetric composition may also account for the varied effects of waste glass and cullet on mortar consistency.

This study aims to discover the effect of adding different amounts of PET on the properties of concrete and recommend appropriate usage suggestions from an engineering and environmental point of view.

2. Experiment

Three waste materials were chosen in this study: PET, tires, and glass. Different experiments were carried out to investigate their effects on concrete properties. In addition, a comparison was conducted between them to evaluate their efficacies. The crushed tire rubber with a diameter of about 2.36 mm will be used to replace the sand. The particle size analysis, density, moisture content, water absorption, and density of the aggregates used were analyzed in the laboratory.

2.1. Materials

The grain size analyses test is utilized to find out the proportion of every type of grain in the soil sample, and the data can be used to generate a distribution curve of grain sizes. There sieve analysis was used to determine grain size distribution (for particle sizes bigger than 0.075 mm in diameter). A sample of each type of aggregate used in concrete mixes was analyzed according to ASTM C136 / C136M - 14 [12], and ASTM D75 / D75M [13]. The results are presented in the figures below (figure 2 & figure 3).

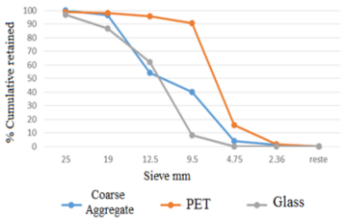


Figure 2. Coarse aggregates curves.

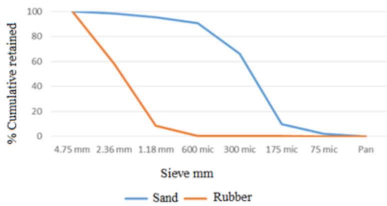


Figure 3. Fine aggregates curves.

Density, specific gravity, and absorption of aggregates are essential parameters for the design of concrete mixes. All these properties have been analyzed for sand and coarse aggregates according to ASTM D75 / D75M - 14 [13], ASTM C128-12 [14], ASTM C127 - 15 [15], ASTM C29 / C29M - 17 [16] respectively. Each test was repeated three times, the obtained average results are presented in the table below (table 1).

Table 1. Natural aggregates properties.

	Density (dry)	Density (saturated)	% Moisture content	% Absorption coefficient	Density (kg/m^3)
Sand	2.58	2.61	0.45	1.15	1452
Coarse aggregate	2.69	2.72	1.048	0.81	1523.29

Firstly, four mixes of concrete were cast, where each mix had increased amounts of each waste type (figure 2). The first mix is a control mix where normal concrete was prepared with concrete strength equal to 25 MPa. In the rest of the mixes with increasing proportions, rubber was added to replace the sand. However, the coarse aggregates were substituted with PET and glass materials. Note that the used proportions replaced the component by the following percentages: 10%, 15%, and 20%.

9 concrete mixes were prepared in the laboratory, for each mix 7 cylinders (15 cm × 30 cm) were cast according to ASTM C192 [17], in addition to a beam with dimensions (15 cm × 15 cm × 75 cm) according to ASTM C31 [18]. The interiors of all the molds were properly greased to have an easy removal of the hardened cylinder, at the testing time. The mixed concrete was placed into the plastic molds through 3 layers. Using a hard steel rod, each layer was compacted with 25 strokes. The targeted concrete compressive strength is 25 MPa. Furthermore, the water-cement ratio (W/C) was determined depending on the required compressive strength.

2.2. Preparation Method

In the initial phase of the experiment, the different coarse aggregate was partially replaced by PET. The sand replaced by PET was related to the volume and not to the amount of its mass. The dry components were added to the concrete mixer (Pan Type concrete mixer) for a few minutes. After that, the water was added gradually to ensure the homogeneity of the mixture. The final preparation phase before testing is the sample curing. All the samples were cast, and by the next day, they were immersed in water tanks, inside the laboratory with a recorded temperature equal to 28°C.

3. Results and Discussion

Three cylinders were tested on the 7th day, and three others on the 28th day. The last cylinder was tested for the determination of the indirect tensile strength. In addition, for each mixture, the beam was tested for the determination of the flexural strength at 28th days.

3.1. Concrete Slump Test

The purpose of the concrete slump test is to evaluate the workability or consistency of the laboratory-prepared concrete mix. There is a recommendation for the slump test limits depending on the concrete construction elements (foundations, beams,…) which ranged from 25 mm as a minimum limit, to 100 mm as maximum limit. For the control sample, the obtained slump value was 6.5 cm [19]. However, all the results for the different waste samples (10%, 15%, and 20%) were summarized in figure 4.

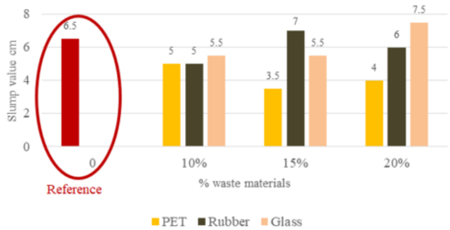


Figure 4. Slump test results.

3.2. Compressive Strength

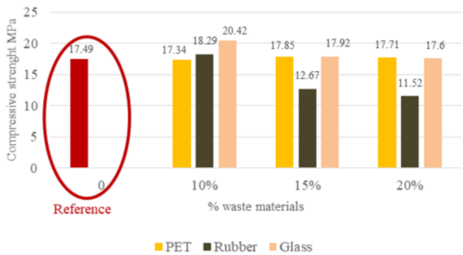
The compressive strength of concrete (f_c') is the strength of hardened concrete. It consists of measuring the ability of the concrete to resist compressive loads without cracking or deflection. The compressive strength was measured using a mechanical testing machine according to ASTM C39/C39M-21 standards [20]. A compressive load is applied longitudinally to the cylinders to measure their compressive strengths. This resistance is determined by the ratio of the applied force (kN) and the cylinder surface area (mm^2).

After sample curing, the specimens were placed in a compression-testing machine, and loaded until failure (The load just before failure was recorded). To assure that the load will be applied to the total area of the concrete cylinder, a hard steel plate was applied on its top.

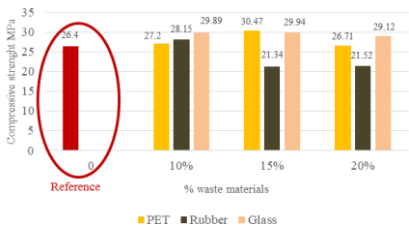
For the reference cylinders (0% waste), the obtained results of the compressive strength on the 7th day (17.49 MPa) represent 70% of the strength on the 28th day (25 MPa).

However, for mixtures containing rubber as a partial sand replacement, the results show a gradual decrease in compressive strength with increasing rubber content. For a replacement of 10% of the sand, the resistance at 7 and 28 days appeared similar to that of the reference concrete.

Furthermore, for the samples containing glass, on the 7th day, the compressive strength of the mixture with 10% of the glass increased compared to that of ordinary concrete. This value decreased again with the increase in the replacement rate to 15 and 20% to return to a value similar to that of the reference concrete. The obtained results are summarized in figure 5 (a, b).



(a) Results at 7 days



(b) Results at 28 days.

Figure 5. Compression Test.

3.3. Split Tensile Strength

The tensile strength of the concrete is described by the ability of the concrete to resist the pull force without cracking. Its value should be between 10% and 15% of the compressive strength of concrete. The strength of the concrete can be determined by dividing the sum of applied forces in the direction of tension (kN) over the surface area of the cylinder (mm^2).

Tensile strength testing was performed on the 28th for all concrete mixes. For ordinary concrete, the tensile strength is reduced by 10.52% (2.63 MPa) compared to the compressive strength studied (25 MPa). For cylinders with partial replacement of sand by tire rubber, the tensile strength increased up to 3.04 MPa for a replacement rate of 10% and then this value decreased again to reach 2.20 MPa and 2.19 MPa for replacement rates of 15% and 20% respectively (figure 6).

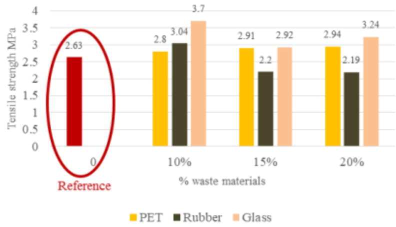


Figure 6. Tensile test at 28 days.

3.4. Flexural strength or Rupture modulus

Flexural strength is a measure of concrete tensile strength. It is the ability of an unreinforced concrete beam to withstand bending failure. This deformation is characterized by its deflection. For concrete beams, bending tends to bring its two ends closer together. It is calculated by loading a beam of concrete with a cross-section (b x d = 15 cm x 15 cm), and a length that is not less than triple its depth (L = 3d).

The bending test was carried out for all the beams on the 28th day. The flexural strength of ordinary concrete is 5.5 MPa. This value decreased to reach 4.2 MPa and 5.2 MPa for the substitution of sand for 20% of rubber and coarse aggregates by 20% of plastic or glass respectively. All the obtained results are presented in figure 7.

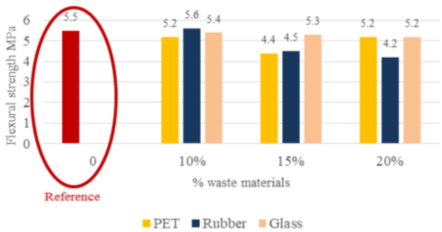


Figure 7. Flexural Test (28 days).

4. Conclusions

The obtained experimental results for the concrete mix where the sand is replaced by PET, after testing 30 cylinders in compression and tensile strength, has low resistance to external loads. The obtained results of the tests carried out so far give hope for profitable future use.

The compressive strength decreased with the increase in the percentage substitution of sand for rubber. However, in the case of the replacement of coarse aggregates by plastic particles or glass, the compressive strength increased or remained similar to that of ordinary concrete.

The tensile strength increased when replacing large aggregates with plastic or glass (10%, 15%, and 20%) and it decreased when replacing sand with 15% and 20% rubber.

The flexural strength decreased by comparing to the reference concrete for all tested waste substitution cases.

From these results, it can be seen that the use of solid waste in concrete mixes keeps an acceptable value for compressive and tensile strength, which makes the use of solid waste in construction very effective.

It can be concluded that an acceptable compressive strength has been obtained with a replacement of up to 20% by volume of coarse aggregates by PET or glass particles, whereas the substitution of sand by rubber powder is optimal for a 10% replacement rate.

However, the effectiveness of the presence of solid waste in concrete in the long term and under different climatic conditions should be verified.

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