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EXPERIMENTAL EVALUATION OF POLYMER LATEX EFFECT ON DURABILITY OF CONCRETE RECYCLED WITH PLASTIC WASTE

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ABSTRACT

In this study, we examined the effect of applying the waste plastics made of high-density polyethylene and polymer latex simultaneously on the physical properties and durability of concrete. For this purpose, high-density polyethylene has been substituted by sand in the amount of 10, 20, 30, and 40% volume. One percent of polymer latex has been substituted by cement. This study aimed to answer one question: "What are the effects of polymer latex on the durability of concrete containing high-density polyethylene plastic aggregates? According to the results, increased plastic wastes made of high-density polyethylene in addition to polymer latex leads to increased consistency, decreased density, increased percentage of air content, increased water absorption as well as the permeability of chloride ions. The samples lack of plastic wastes containing 1% of polymer latex in comparison to the reference sample showed 7% more slump and 17% more air in fresh concrete, 25% more chloride permeability, and 60% more water absorption. Also, the sample containing 40% waste plastic in addition to 1% polymer latex showed 33% more slump, 9% less density, 275% more air content, 133% more chloride ion permeability, and 240% more water absorption compared to the reference sample.

INTRODUCTION

One of the most important materials in the construction industry is concrete. About 75% of the concrete volume is consisted of aggregate [1]. Nowadays, due to the widespread use of concrete, aggregate production resources are decreasing. Otherwise, a large volume of plastic waste is produced daily. Plastic waste is burnt, buried, or left in the ocean, leading to air, soil, and water pollution[2]. Only a small percentage of plastic waste is recycled. One of the methods for plastic recycling is using it as aggregate in concrete. In this way, the non-renewable sources of aggregate production will not be faced with a crisis and will help address environmental issues and prevent renewable sources of aggregate production from becoming depleted. Therefore, the necessity and importance of using plastic waste in concrete are felt more than ever. In Europe, the largest volume of plastic waste is about 23% light polyethylene (LDPE), then polypropylene (PP) with 18.5%. Also, high-density polyethylene (HDPE) is 17.3%, polystyrene (PS) with 12.3%, polyvinyl chloride (PVC) with 10.7%, polyethylene terephthalate (PET) with 8.5%, and other types with 9.7% of plastic waste volume [3].

In most parts of the world, research has been done on the properties of concrete produced with recycled plastic aggregate. Rumsys et al.[4] (2017) examined the effect of aggregate from plastic waste on mechanical properties of high strength light concrete and comparison with concrete containing expanded clay aggregates. For this purpose, plastic aggregate made of light polyethylene (LDPE) and high-density polyethylene (HDPE), as well as cement-replacing minerals, was used. Compressive strength, tensile strength, water absorption, and density of 12 samples were measured. The results showed that the concrete has plastic aggregates made of lightweight polyethylene and high-density polyethylene (HDPE). The concrete has a specific weight of 2050-1950 kg/m3 and compressive strength of 40 MPa for 28 days. In addition, the use of expanded clay aggregates leads to the reduction of the density of 1900 kg/m3 and an increase in compressive strength of 70.2 MPa.

Kapoor et al.[5] (2016) examined the efficiency and durability of self-consolidating concrete containing recycled aggregate and cement alternative minerals. Recycled aggregates of crushed concrete (0, 50, and 100%) were replaced with normal aggregates. Also, Metacolin and Microsilica were used in replacing cement by 10% wt. Then nine laboratory specimens were tested under slump test, compressive strength, the permeability of chloride, initial surface absorption, water penetration, and initial suction. The results showed that the addition of silica fume and metacolin could compensate for the decrease in the durability of concrete containing recycled aggregates. The results showed that the addition of silica fume and metacolin could compensate for the decrease in the durability of concrete containing recycled aggregates. In addition, during replacing total recycled aggregate with normal aggregate, silica fume and metacolin have no effect on compensation properties due to aggregate replacement.

RESEARCH METHOD

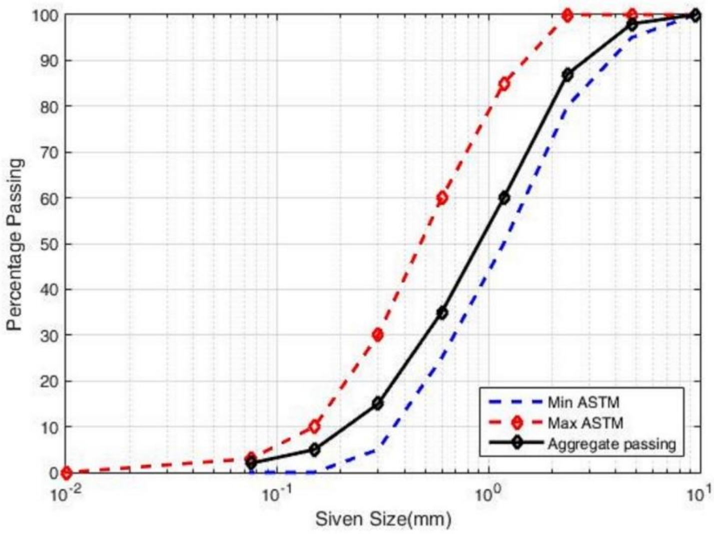
The main objective of this study was to investigate the simultaneous effect of waste High-Density Polyethylene (HDPE) in addition to Styrene-Butadiene Rubber (SBR) on the physical properties and durability of concrete. Therefore, High-Density Polyethylene (HDPE) was used as a sand substitute and for the sand at the volume of 10, 20, 30, and 40%. Latex was used as a substitute for Portland cement by 1% wt. In the first step of the research, previous studies were reviewed. In the next step, the concrete constituents such as water, stone materials, cement, high-density polyethylene waste, latex were described. Then, the mixing design according was prepared according to the obtained percentages of high-density polyethylene (HDPE) and latex regarding ACI regulations. The physical properties of the samples were determined using the slump tests and the air content. Also, water absorption and permeability of chloride ions were used to determine the concrete durability. Finally, results are interpreted and discussed following some examination.

MATERIAL AND MIXING DESIGN

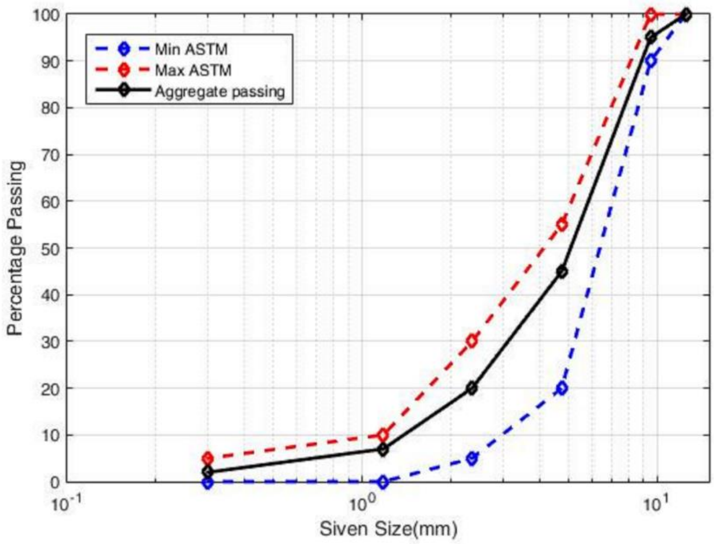
Material

The water consumed for the production of concrete is one of the most important factors that have a significant effect on the quality of concrete. The use of unsuitable water for mixing concrete will cause corrosion in the concrete structures, disruption of cement set, and low strength of concrete [6]. Generally, in many technical specifications, the desired water for mixing concrete is drinking water. Therefore, in this study, drinking water was used for mixing concrete. Another component of concrete is cement. Portland cement is actually obtained by combining iron material such as gypsum or limestone, aluminum, and silica produced from shale or clay [7]. In the construction industry, there are different types of Portland cement to solve certain engineering problems. Their chemical composition is also different. However, most cement consumed in the building industry today is Portland type II. In this study, Portland Type II cement was used. Aggregates are other materials that affect the properties of concrete. Normally aggregates usually make up 70-80% of concrete volume [8]. Stone materials are prepared by the process of wear and weathering or artificially breaking the larger parts of the mother stone [9]. Therefore, many properties of stone materials, such as density, depending on bedrock. On the other hand, stone materials have other properties such as particle size and shape that do not exist in bedrock. All of these properties have a significant effect on the quality of fresh or hardened concrete. Therefore, in order to prepare suitable concrete, all properties of aggregates should be recognized. Aggregates with 2.6 ton/m3 density were used. In addition, the aggregations test for particle size distribution was determined by the ASTM C33 standard [10]. The particle-forming curve of stone materials is shown in Figure 1.

High-density polyethylene is an oil derivative. This type of polymer has high strength and low flexibility [11]. These two characteristics have caused the polymer to produce toys, water pipes, industrial and sewage pipes, plastic sports supplies, fuel containers, open spaces chairs, etc. [12]. Due to the many applications of this type of plastic, large quantities of it are produced annually, and a considerable part of it is recycled after consumption. As shown in Fig.2, in this study, high-density polyethylene has been used as a round corner with a density of 0.958 tons/m3. Also, it has been used in volume fractions of 10, 20, 30, and 40%. The Styrene-butadiene latex (SBR), which has been shown in Figure 2, is polystyrene and butadiene copolymer, which has a ratio of more than 50% butadiene. The polymer latex, discovered in the twentieth century, has numerous applications due to its easy access and inexpensiveness, such as the preparation of gaskets, straps, and coils. [14]. The use of polymeric latex as a cement substitute for the improvement of structural concrete properties in recent decades is expanding [15]. In this study, a polymer latex with 1 vol.% cement was used. The density of PFC latex used in this study is 0.95 ton/m3. In some cases, instead of using special cement, common cement can be used with additives. For example, in places where lubricant and resistant concrete is required, super lubricant can be used. In this study, according to ASTM C 494 standard in concrete mixing design to achieve the desired slump (7 - 10 cm), super lubricant 1% is used.



A



B

Figure 1: Grading curve of Rock Materials (A) Fine-Grained (B) Coarse-Grained

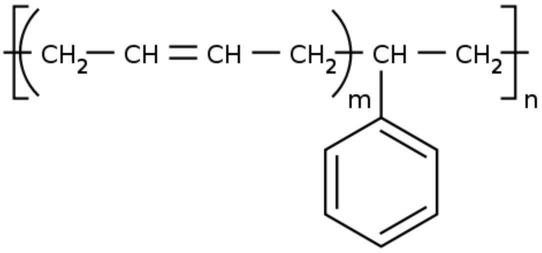


Figure 2: Chemical Structure of Repeating Polymer Latex Unit (SBR)

Mixing Design

The first step for preparing suitable concrete is to select high-quality materials. In the next step, the mixing ratio should be correctly determined. The last step is the correct execution of mixing ratios that guarantee the quality of concrete. The determination of mixing ratios or mixing patterns can be defined. The process of determination of weight values of cement and water sand in order to provide economic concrete with the minimum required properties such as strength, durability, and mental strength [16]. In this study, the American method of mixing design for normal weight concrete (ACI211.1-19) is used. The specifications of the mixing design used for the construction of all concrete samples (volume 0.055 cubic meters) are shown in Table 1.

Table 1: Experimental Samples Mixing Design

Sample	Cement (kilogram)	Coarse-Grained	fine-grained	The ratio of water to cement	high-density polyethylene	Polymer latex		Water (kilogram)	Lubricant (%)
						(kilogram)	(%)		
HC0-1 (Reference)	25.3	45.82	43.06	0.38	0	0	0	9.6	1
HC0-2	25.05	45.82	43.06	0.38	0	0.25	1	9.6	1
HC10-1	25.3	45.82	38.76	0.38	1.54	0	0	9.6	1
HC10-2	25.05	45.82	38.76	0.38	1.54	0.25	1	9.6	1
HC20	25.05	45.82	34.50	0.38	3.10	0.25	1	9.6	1
HC30	25.05	45.82	30.20	0.38	4.60	0.25	1	9.6	1

HC40	25.05	45.82	25.80	0.38	6.20	0.25	1	9.6	1

EXPERIMENTS METHODOLOGY AND INTERPRETING RESULTS

Since there is a lot of diversity in concrete technology experiments, it is not possible to do all of them because of economic and executive constraints, while in that case, the conclusion will be hard. Therefore, planning for conducting the experiments should be done carefully so that the results can be reached quickly. The main objective of this study is to investigate the physical properties and durability of concrete containing high-density polyethylene waste (HDPE) plus latex. In this regard, to evaluate the physical properties of concrete samples, the experiments were performed for the slump, current density, and air, and to evaluate the durability of concrete samples, surface adsorption, and permeability of Chloride ions were used. Then the methods of conducting the experiments, as well as their results, are presented along with their interpretation.

Slump Test

Water is commonly used for cement setting and hydration operations and also for building concrete performance. The amount of water is usually between 40% and 50% of the weight of the cement. Excess water will evaporate, and it will remain attached to each other as capillary holes, and the concrete will be hollow, and its resistance will decrease. Increased water to concrete causes consistency. Consistency is concrete ability or newly mixed mortar for consistency [17]. At the same time, performance means ease of shedding, polishing, concrete compression capability, and resistance to separations [18]. So far, there is no experiment that could directly demonstrate the performance of the concrete. It has always been tried to measure performance with some simpler physical properties. One of these experiments is a slump. It means to fall and settle down. This experiment is widely used in workshops. It should be noted that this test does not measure the efficiency of concrete, but it is used to describe the concrete's consistency properties. Therefore, the main purpose of this experiment was to determine the consistency degree of concrete dough and ensure the performance of the concrete mixture components [19]. This test has been described in the ASTM C143 regulations, and according to the results of this study, the test has been done for the slump test. First, the experimental die, which is a deformed cone, was placed on a smooth surface, and then it was filled into three layers. Each layer was hammered with 35 strokes of the steel bar. The conical cone was slowly drawn up, and the concrete came out of the mold and settled down. The decrease in the height of concrete was noted as a slump.

The results of the slump test are reported in Table 2. As shown in Table 2, it is observed that the addition of polymeric latex to the reference specimen caused a 7% increase in the concrete's consistency. Moreover, the HC10-1 sample compared with the reference sample showed that the addition of high-density PEG plastic waste to the reference concrete led to an increased consistency at 13%. Comparing the HC10-2, HC20, HC30, and HC40 samples, it is observed that adding high-density polyethylene by polymer Latex caused an increase in concrete consistency in 17, 20, 27, and 33%, respectively, in comparison with the reference sample. It seems that this consistent growth of concrete is due to the lack of water absorption of recycled aggregate.

Density Test

Normal concrete density is about 2400-2500 kg/m3. So the dead weight of concrete parts is relatively high. One way to prevent damage is to reduce the weight of dead structures during an earthquake. For this purpose, lighter materials can be used for the production of concrete. In this study, the ASTM C138 standard was used to investigate the effect of plastic aggregates on the density of concrete samples. As shown in Table 2, the comparison between the reference sample and HC0-2 sample also indicates that the addition of polymer latex only has no effect on the change in the volume density of concrete. With adding plastic waste materials at 10%, 20%, 30% and 40%, the concrete density decreased by 3%, 5%, 7% and 9%, respectively. The reduction in concrete density by increasing the percentage of recycled plastic materials is due to the lower density of recycled aggregate than the normal aggregate.

Table 2: Density and slump values of laboratory samples

Sample	**waste High-density polyethylene (Percentage by volume of aggregate)**	**Polymer latex (Percentage by weight of cement)**	**Volumetric density (Kg per cubic meter)**	**The ratio of the volumetric density of the sample to the volumetric density of the reference sample**	**slump (Mm)**	**The ratio of sample slump to the reference sample**
HC0-1 (reference)	0	0	2255.09	1	75	1
HC0-2	0	1	2255.09	1	80	1.07
HC10-1	10	0	2204.90	0.97	85	1.13
HC10-2	10	1	2204.90	0.97	88	1.17
HC20	20	1	2155.81	0.95	90	1.2
HC30	30	1	2204.90	0.93	95	1.27
HC40	40	1	2055.00	0.91	100	1.33

Available Air Test

The amount of air in the fresh concrete is an important component for concrete that is subject to intense contraction and expansion caused by frost. Water after penetration into the concrete and freezing cavities will increase volume and cause the concrete to crack and shell. Therefore, it is essential to determine the amount of air in concrete that is one of the factors that affects its durability. In this study, the existing method in the ASTM C231 standard has been used. In this experiment, we first put fresh concrete in a tank and in three layers. In each layer, concrete is combed using the rod to compress concrete into the chamber. Then, by measuring the volume change due to wind pressure, the amount of air in concrete has been recorded. The percentage of air in concrete samples is shown in Table 3.

Table 3: Air Content in Fresh Concrete Samples

Sample	High-density polyethylene (Percentage by volume of aggregate)	High-density polyethylene (Percentage by volume of aggregate)	Polymer latex (Percentage by weight of cement)	Available air (Percentage)	The ratio of sample air to reference sample
HC0-1 (Reference)	0	0	0	1.2	1
HC0-2	0	0	1	1.4	1.17
HC10-1	10	10	0	1.5	1.25
HC10-2	10	10	1	1.8	1.5
HC20	20	20	1	2.43	2.025
HC30	30	30	1	3.3	2.75
HC40	40	40	1	4.5	3.75

As observed, the HC0-2 sample has more air than the reference sample at 17%. In other words, the addition of PFC latex on its own increased the air content of the fresh concrete. The HC10-1 sample contains more air than the reference sample of 25%. It is concluded that the addition of plastic waste material made of high-density polyethylene alone will increase the air content of the fresh concrete. Also, by increasing the amount of plastic waste material of high-density polyethylene (HDPE) in the concentration of 10%, 20%, 30%, and 40% in the polymer latex solution up to 50%, 102.5%, 175%, and 275%, respectively, the air in fresh concrete has been increased.

Ion Chloride Permeability Test

In this study, the Ion Chloride Permeability Test is done based on the ASTM C1202 standard. In this experiment, a cylindrical specimen with 100 mm diameter and 50 mm thickness is used. One side of the concrete sample was covered by epoxy. After three hours of epoxy drying, the sample was put in a vacuum chamber. Samples were stored in a vacuum for one hour and then in saturated water for 18 hours. The experimental sample was placed between two containers, one containing sodium hydroxide and the other containing sodium hydrxide. After 6 hours, the sample was supplied with 60 volts of electricity. Then, the total electric charge passing through the concrete specimen was measured, and based on the strength of concrete against the permeability of the concrete ion was determined. The amount of Ion Chloride permeability for samples is shown in Table 4.

Table 4: Amount of Ion Chloride Permeability for Laboratory Samples

Sample	High-density polyethylene (Percentage by volume of aggregate)	Polymer latex (Percentage by weight of cement)	Chloride ion permeability (Mm / s)	Chloride ion permeability ratio of sample to reference sample
HC0-1 (Reference)	0	0	5.40	1
HC0-2	0	1	6.73	1.25
HC10-1	10	0	7.10	1.31
HC10-2	10	1	7.54	1.40
HC20	20	1	8.60	1.59
HC30	30	1	9.80	1.81
HC40	40	1	12.60	2.33

As observed, the addition of polymeric latex only increased the permeability of chloride by 25% in comparison to the HC0-2 sample. The permeability of the HC10-1 sample containing 10% recycled aggregate is 31% higher compared to the reference. Also, by increasing the amount of plastic waste material of high-density polyethylene (HDPE) in 10%, 20%, 30%, and 40% with polymer latex (PEC) of 25%, 40%, 59%, 81%, and 133%, respectively, the permeability of chloride has increased.

Water Absorption Test

This test was done according to the ASTM C642 standard. For this purpose, laboratory samples were put in a hot chamber for 24 hours at 100-110 °C. After removing from the hot chamber, the weight was recorded and put in the basin for five hours. After removing the basin and drying its surface, the weight was noted. Finally, the amount of water absorbed in Table 5 was calculated.

Table 5: water absorption of samples

Sample	High-density polyethylene (Percentage by volume of aggregate)	Polymer latex (Percentage by weight of cement)	water absorption (percentage)	The ratio of sample water absorption to reference sample
HC0-1 (Reference)	0	0	0.05	1
HC0-2	0	1	0.08	1.6
HC10-1	10	0	0.09	1.8
HC10-2	10	1	0.11	2.2
HC20	20	1	0.13	2.6
HC30	30	1	0.15	3.0
HC40	40	1	0.17	3.4

As observed, with the addition of polymeric latex to the concrete sample, water absorption increased to 60%. Comparison of HC10-1 sample with reference sample shows that the addition of 10% high-density polyethylene increased water absorption at 80%. Water absorption of the samples increased by increasing the plastic waste material (10%, 20%, 30%, and 40%) with polymer latex (60%, 120%, 160%, 200%, and 240%, respectively) compared to the reference sample.

CONCLUSION

Based on the results of the experiments performed on the concrete specimens, the following results were obtained.

1-Compared with the reference sample, the HC0-2 sample has 7% more Slump and 17% more air content in fresh concrete, 25% more Chloride permeability, and 60% more water absorption. In other words, the addition of polymeric latex in normal concrete by one percentage weight of cement will reduce the concrete durability.
2-Ten percentage increase in plastic waste material to reference sample results in 13 percentage increase in slump content, 25 percent increases in air quality, 31% increase in permeability of Chloride, 80% increase in water absorption, and 3% decrease in concrete density. Therefore, the addition of waste material in concrete reduces the durability of concrete.
3-Comparing the reference sample with HC0-2, HC10-2, HC20, HC30, and HC40 samples, increasing the percentage of plastic waste with polymer latex increases the percentage of concrete air. The strength of concrete and its durability decreased by increasing the percentage of air.
4-Increasing the percentage of plastic waste material with latex increased the amount of water absorption and ion chloride permeability. The concrete's durability properties decrease.

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