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An investigation of the use of plastic waste as aggregate in concrete

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Abstract

Plastic waste (PW) is one type of solid waste. Its disposal and management pose environmental concerns in several countries around the world. PW causes serious problems for land, soil, & water. Recycling of PW is an innovative idea or way in this field, to produce new materials like plasticized concrete (PC), or rubberized concrete, which appears as one of the best solutions for disposing of PW, due to its economic and ecological advantages. Also, with the rapid growth and development in the construction industries with higher demands for concrete, emphasis has been laid on the sustainability of the concrete constituent materials. This study explores the ameliorative effects of plastic particles (PP) on some properties of concrete. The main aim is to study, and analysis of the mechanical, acoustical, & thermal properties of sustainable concrete incorporating PP & compared it with the traditional one or normal concrete (NC). The percentage of PP used in this study varies from 0-25%. The overall results show the addition of PP to the NC to obtain a lightweight one. It caused a reduction in the compressive strength by about 40-51% from NC. Also, the added PP decreased the thermal conductivity of the PC by about 50% from NC. However, PC improved sound absorption & thermal conductivity. Results have shown that the increasing contents of PW of concrete reduced the ultrasonic pulse velocity and the intensity of sound passing through PC. The significance of this study is to provide information to reuse, reduce, and recycled solid waste (i.e., PW) & to help future researchers both in academics and in the world, Civil engineers /Structural designers/Builder, etc. with dependable information on the use recycled materials for concrete production.

Keywords: *Waste Management, Waste, Plastic, Environment, Construction.*
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I. INTRODUCTION

Solid waste management is one of the major environmental issues in our modern life. The use of recycled materials as aggregate replacement in concrete for construction purposes has been proven to be a sustainable solution to the problem of waste disposal and natural aggregate depletion in all developed countries around the world. Presently, the earth confronts many environmental issues such as disposal of waste, pollution of air, etc. management of solid waste and the environment constitutes the main challenge in Iraq and it must be at the top of the decision-makers' list of priorities. In recent years, an emerging technology termed, ''Green concrete (GC)'' has become popular in the construction industry. GC can be defined as concrete cast with wasted materials, such as plastic waste (PW), crumb rubber, etc. At the moment, plastic waste (PW) disposal is becoming a main waste management issue in the world. It is estimated that the world currently creates more than 2 billion tons of solid waste (SW) every year [1]. In 2015, it was estimated that Iraq produces 31,000 tons of solid waste per day and 1.5 million tons per year [2]. As the amount of solid waste generated has increased in recent years, solid waste management (SW) has been confirmed to be a rather difficult problem. Recently, the management of solid waste has become an important part of our economy, being a secondary output of economic activity and created by households, businesses, and governments. Also, solid waste can be applied as an economic activity input, for example, through the recovery of energy or substances [3]. Solid waste management (SWM) involves the protection, characterization, controlling, remediating, and reusing of solid waste. SW remediation is the process of SWM, which offers a set of ways to recycle and reuse things [4].

Pollution from plastic waste has come to be a great problem around the world, including Duhok City, Iraq. Invisible microplastic waste can be found in soil and water. Visible plastic waste in the oceans, land, or soil. Petrochemical leftovers from

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plastic creation blanket our planet, so the quantity of plastic waste (PW) created is set to increase dramatically. With the creation of petrochemicals, a high percentage of carbon was released into the atmosphere [5].

There is a growing interest in using solid waste materials (SWM) as alternative aggregate materials and significant research has been conducted on the use of many different materials as aggregate substitutes, such as fiberglass waste materials, PW, rubber waste, and others. This type of SWM application can solve aggregate shortage issues at various construction sites while also reducing environmental issues associated with aggregate mining and waste disposal. The use of waste aggregates can also reduce the cost of concrete production. Since the weather in Iraq is too hot in the summer and the thermal conductivity of concrete is too high, we must use air conditioning. Air conditioning requires electricity, and Iraq has an everlasting deficiency in power generation. Much pollution is produced during the production of electricity. PW recycling gains importance because it can increase the insulation of concrete and decrease the thermal conductivity of concrete. Hence, less electrical energy consumption. Since PW accumulates, making it disposed of in a sanitary manner is difficult. In the case of protecting the environment from the worsening problem, PW recycling is a new model or idea. PW used in concrete can be a cost-effective way to use in civil construction materials while also providing environmental benefits. By replacing the partially fine aggregates in concrete with the PW. Concrete that contains PW could have perfect properties of engineering, or better substance qualities to be utilized in many applications. The purpose of that study was to minimize the PW as a better solution for protecting the environment, i.e., reducing the PW in Duhok, Iraq, and reusing this SW with another material [e.g., aggregate filler, mixed with the concrete].

II. Plastic Waste

In 2012, it was estimated that around 280 million tons of PW had been created in the world. Of those quantities, around 130 million tons of PW were recycled or land-filled. Around 150 million tons of stayed PW will be detected in the everyday lives of humans [6]. In 2016, production of the PW was raised to 335 million tons internationally, and in Europe it was 60 million tons. From the statistical data that was mentioned, waste recycled was 31.1%, waste used for the recovery of energy was 41.6%, and 27.3% of that waste was landfilled internationally in 2016. Moreover, the production of plastic in 2035 is rated to be doubled, and by 2050, it is estimated to quadruple. The industry of construction can be used for several purposes because it is the largest industry in the various economies and the largest consumer of raw substances. Civil construction substances can use PW in the form of aggregate in the mixture of concrete, insulation, and filler [7]. PW in the environment causes various impendences to the modern community because it consists of various dangerous chemicals, and PW contaminates water, soil, and air if not treated or completely managed. As a result, most plastic waste today is of non-biodegradable origin, and PW land-filling entails burying the harmful substance for long periods of time until it degrades naturally. Any PW, in its natural case, would raise the size of waste during land-filling. In the application of civil engineering, reusing plastic waste in a construction material such as the mixture of concrete is shown as the best choice for alternate disposal of the PW. This will be due to environmental and economic advantages which can replace a certain part of the aggregate in the mixture of the concrete [8]. In some research, plastic waste was used in the concrete mix collected from the plastic factory and waste treatment plants [6]. Concrete strength behavior that contained three kinds of recycled polyethylene terephthalate (PET) aggregates. Results were analyzed to determine the effects of PET-aggregates on the relationship between compressive strength and flexural and splitting tensile strength [9]. Pooja, et al. [10], studied the properties of the concrete with part alteration of the fine aggregates with PW 15-30% with little grain size. Making paver blocks from plastic waste and repurposed materials in mixed concrete is becoming increasingly important for treating and managing PW generated by municipal waste and industrial waste [11]. Jibrael and Peter [12] studies the behavior and strength of concrete that contains plastic waste. They replaced fine aggregates with plastic bags and plastic bottles, altering the percentage from 0% to 5%.

Several studies have concentrated on applying waste to create various materials for construction [13, 14]. Concrete has been counted as the major construction substance which is applied to the plurality of virgin substances and is accountable for considerable energy consumption [15]. The primary reasons for the majority of this research are to reduce the impacts on the environment by changing virgin substances with waste substances [13, 16].

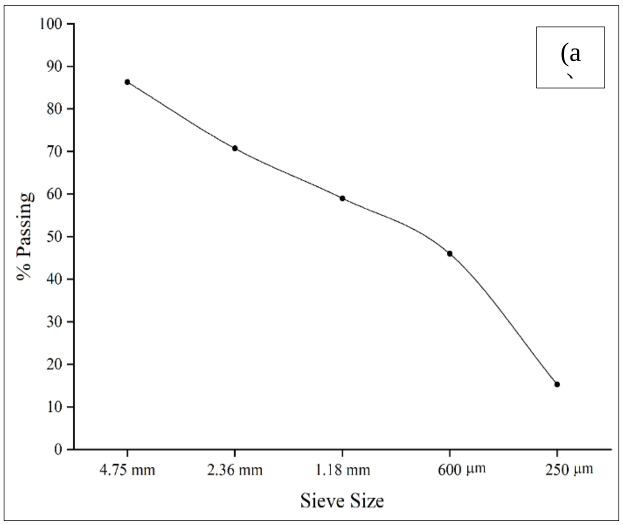
Fig. 1. PET aggregated was used

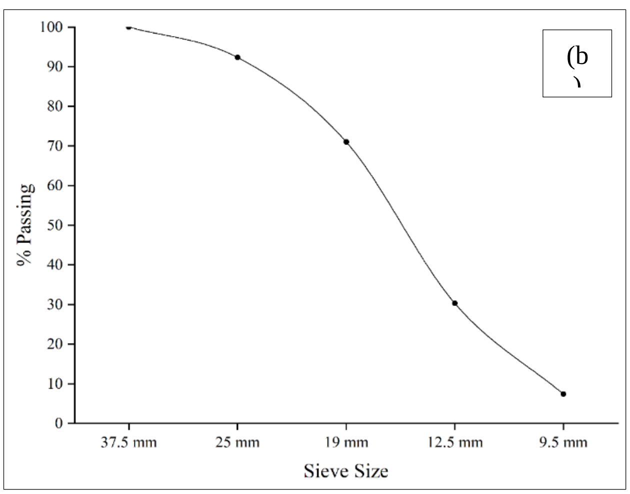
III. Materials and Methods

The used PW was gathered from the workshop in Duhok City, Iraq. PW was recycled. The fine fraction and coarse flakes were collected after the grinding mechanics of PET waste was followed up by a physical separation and cleaning method. Polymer grains and water are subjected to a vibratory separator, and to remove the contained water, the polymer grains are centrifuged. Plastic fine fractions are used as an aggregate of plastic in the creation of concrete structures. According to the standard method, sieve analysis of aggregate Polyethylene terephthalate [PET] was carried out. The aggregates of PET used in this research are shown in Fig. 1.

As shown in Fig. 2, mechanical sieving was used to separate aggregate into various sizes. The grading curve of the aggregate in Fig. 3 is presented.

Fig. 2. Mechanical sieve shaker device from matest company.





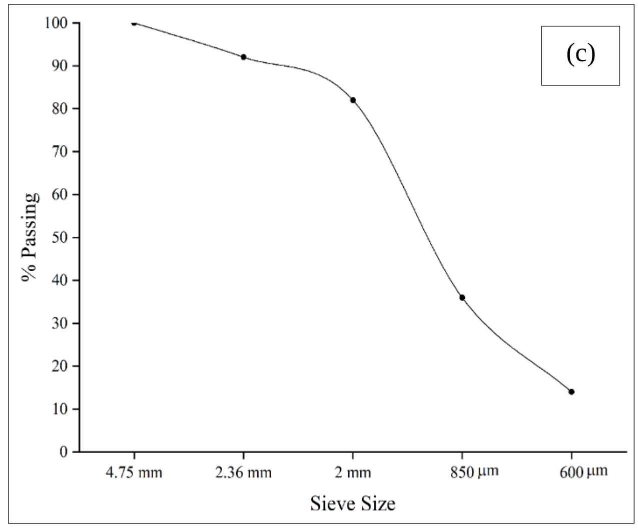


Fig. 3. Sieve analysis of a) fine aggregates. b) coarse aggregates. c) PET waste.

A. Casting Procedure

According to ASTM [17], mineral oil coated the molds before use, and concrete samples of varying thicknesses were cast. Tamping rods in manual position were used to compact each of the samples until no bubbles of air from the concrete surface emerged, and a steel trowel was used to smoothly level off the mold top. Then kept the molds for 24 hours, as shown In Fig. 4.

Fig. 4. Casting method

B. Curing of Specimens

The term "curing" is frequently used to describe the operation by which hydraulic cement ripe concrete and hardened concrete properties develop as an outcome of continual cement hydration in the existence of heat and sufficient water. After the specimens were cast, they were kept for 24 hours in the laboratory until they dried.

C. Moisture curing method

All cubic samples were immersed in a water curing tank at the 21±2 Co and water was controlled by the heater of water until measurement time (28 days).

D. Test Procedures

1) Preparation of concrete

18 samples of concrete with 6 different concrete mixes have been prepared. The volume of the concrete sample was 150mm3. The size of fine aggregates was replaced by 0%, 5%, -25% by adding PET aggregates. The steps for creating the concrete mix, casting it, and evaluating its properties were all standard. Several procedures are applied to measure the concrete hardened state properties (Table I).

TABLE I. THE INGREDIENTS MIX PROPORTION FOR A CONCRETE 150MM^3

Plastic replacement (%)	Cement (kg)	Plastic (kg)	Fine aggregate (kg)	Coarse aggregate (kg)
0	1.370	0	2.055	4.110
5	1.370	0.103	1.952	4.110
10	1.370	0.195	1.757	4.110
15	1.370	0.264	1.493	4.110
20	1.370	0.299	1.194	4.110
25	1.370	0.298	0.896	4.110

2) Compressive strength testing

According to the ASTM [18], compressive strength was determined, 18 cubic samples (150mm^3) after 28 days of curing concrete in water were measured by using a pilot 4 test machine device. Fig. 5 shows the pilot 4-compressive test machine for cubic concrete.

Fig. 5. Universal compressive Test machine

3) Ultrasonic pulse velocity testing

An ultrasonic pulse velocity testing device [pundit instrument] (Fig. 6) was used. It uses a wave of sound to uncover flaws and cracks in parts and substances.

Fig. 6. Sound level meter.

4) Thermal conductivity

This test was done at various temperatures. The sample was cured for 28 days and thereafter measured. A Pro portable meter device for thermal conductivity (Fig. 8) was applied to measure the thermal conductivity. For determining the thermal conductivity of concrete without plastic and with plastic, the method of the hot disk was applied [19], and the specimen was prepared with a special mold.

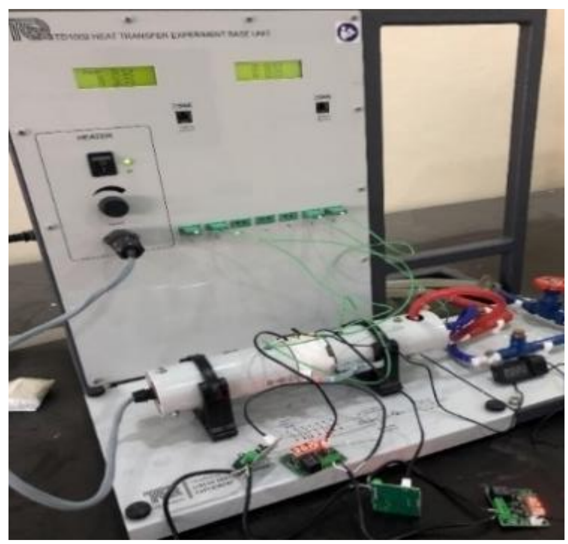


Fig. 7. Heat conduction tecquipment device

IV. RESULTS AND DISCUSSION

A. Compressive strength

According to ASTM [18] this test was done using acompressive pilot 4 machine device. The results of the compressive strength test are shown in Table II. Compressive strength is reduced when the replacement percentage of plastic particles (PP) or PET waste ranges from 5% to 25%. The percentages of 5%, 10%, 15%, 20%, and 25% of PET waste as a replacement of sand lead to a decrease in the compressive strength by 9.5%, 8.8%, 8.2%, 6.8%, and 9.1%. Compressive strength is found to decrease from 36.63 (Mpa) to 17.26 (Mpa) when adding 25% of PW. This is due to the weak bond between Plastic particles (PP) and concrete compared with the bond between concrete, and concrete and this confirmed the results from previous research. In the present study, the average decrease in the compressive strength when adding 25% PP is about 51% of that of normal concrete (NC). These outcomes are consistent with the findings of [20, 21]. Also, these results are compatible with the findings of [22] who applied box particles to plastic waste by 20%, 40%, 60%, and 80%. Moreover, Gopi and Srinivas [23] supported this outcome by applying PET waste particles as a partial alternative to sand in the mixture of concrete with different percentages (5%, 10%, 15%, 20%, and 25%). According to our study, 5% replacement of sand was optimal, and as we increased the PET percentage, compressive strength decreased. We believe that the amount of decrease in the compressive strength may be related to several factors, such as the PET particle size, cement type, water cement ratio, grading, and so on. The failure modes of the concrete containing PET waste are influenced by the form and elastic nature of PET waste granules in such a way that when the load used reaches the final load, the inner stress is transformed from the stress of shear to the stress of tensile. Furthermore, the concrete sample that includes PET granules was not suddenly crushed, but its shape remained with cracks on the surface. This indicates the ductility given by the existence of PET waste compared to sand [24].

TABLE II. COMPRESSIVE STRENGTH OF CONCRETE

Cube name	(%)	28 days			Avg (Mpa)
		1	2	3	
S1	0	37.51	36.69	35.7	36.63
S2	5	32.14	31.81	31.43	31.79
S3	10	27.78	27.35	27.14	27.42
S4	15	24.16	23.81	23.52	23.83
S5	20	21.61	21.36	21.08	21.35
S6	25	17.58	17.22	16.97	17.26

B. Ultrasonic pulse velocity

One of the most important ways to check the quality of concrete is with the ultrasonic pulse velocity test. Fig. 9 shows the ultrasonic pulse velocity of concrete containing PW and concrete without PW. The concrete behaviour that contained plastic waste was similar to that of concrete without plastic waste, especially for samples containing 5% of PET waste. When the percentage of PET was increased to 10%, 15%, 20%, and 25%, the ultrasonic pulse velocity result was decreased by 7.2%, 6.7%, 5.3%, and 8.8%, respectively. This decrease is due to the existence of PET waste in the high amounts of concrete. Consequently, pores and holes were formed within the inside of the concrete. These outcomes are in good compatibility with the findings of [25]. Marthong and Sarma [26] mentioned that increasing the PET waste percentage decreases the concrete quality from excellent to good because the PET waste has a low specific gravity. Plasticized Concrete (PC) has less density than normal concrete (NC). The PC is light for handling. It is identified that the density of concrete decreases when the percentage of replacement of PW increases from 0% to 25%. Marthong and Sarma [26] mentioned that 5% of PET waste can result in samples of concrete with grade quality and ultrasonic pulse velocity (3.5-4.5 km/s). According to the results of this test, replacement of fine aggregates with PET waste at a high percentage has a negative effect on the properties of concrete. Hence, it cannot be recommended. The percentage of plastic waste increased in the concrete may decrease the quality of concrete. It can contribute to the block formation or layers isolated between the components of concrete according to the previous studies [27, 28]. The positive side of these outcomes is that they use a low percentage of PET waste, producing the possibility of making concrete using PET waste, thereby being helpful to the management of plastic waste PET and creating a positive influence on the environment.

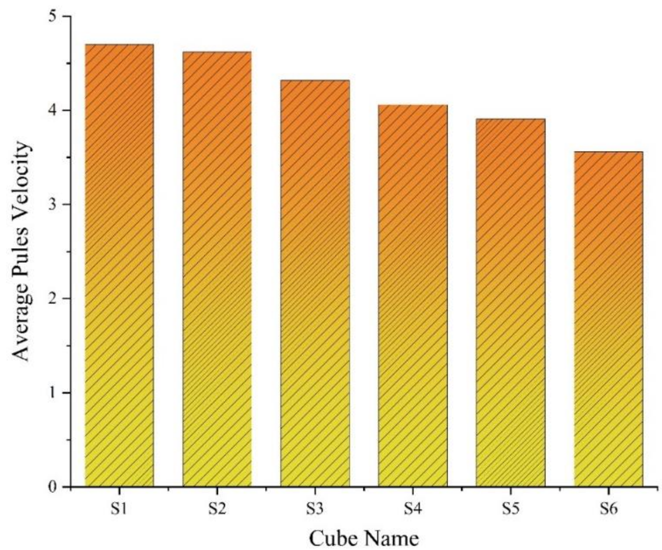


Fig. 8. Ultrasonic pulse velocity

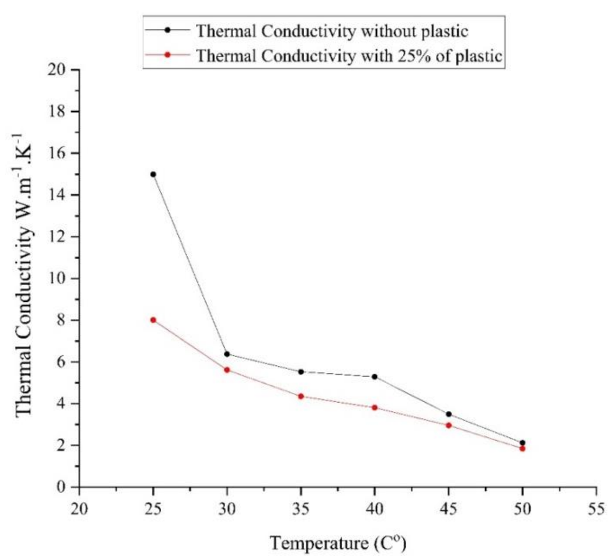


Fig. 9. Thermal conductivity of concrete.

C. The Intensity of Sound

Table III shows the results of the intensity of sound before and after passing through concrete. The samples were tested after 28 days of curing concrete. The purpose of this test is to determine the sound level that passed through regular concrete and concrete mixed with PET waste. Outcomes show that the replacement of PET waste as a substitute alternative to sand has an important impact on decreasing the sound intensity. According to this test, the more PET waste used, the greater the transmission of sound through concrete loss. When the percentage of PET waste increased to 5%, 10%, 15%, 20%, and 25%, the intensity of sound declined by 20.1%, 21.4%, 25.0%, 31.2%, 33.4%, respectively. The decline is due to the addition of PET waste to the mixture of concrete. According to the previous studies that related to sound tests on concrete, only the sound absorption of concrete was measured, but we conducted this test on the concrete mixed with PET waste for the first time, and the results were optimal, especially when PET waste was added. Sound intensity decreased. Sound absorption increases with increasing PP content. This may be due to the ability of the sound to be absorbed by the entrapped air on the PP surface.

TABLE III. THE INTENSITY OF SOUND OF CONCRETE

		Before Passing				After Passing			
Cube name	(%)	Max (dB)	Min (dB)	Average (dB)	Sound reduction index (R) in (dB)	Max (dB)	Min (dB)	Average (dB)	Sound reduction index (R) in (dB)
S1	0	85.1	61.2	73.1	20	73.9	57.1	65.5	12.9
S2	5	84.9	70.7	77.8	10.3	63.2	55.7	59.4	3.6
S3	10	84.5	68.5	76.5	12.1	59.3	54.6	56.9	0.8
S4	15	85.3	70.3	77.8	11.1	55.4	50.8	53.1	0.7
S5	20	84.7	69.4	77.0	11.4	48.8	44.3	46.5	0.6
S6	25	83.4	72.1	77.7	7.4	45.9	41.7	43.8	0.3

D. *Thermal conductivity*

In past years, the study of the mechanical properties of concrete has received more attention from most researchers. Recently, more research has assessed thermal conductivity in the concrete mechanical properties due to the significance of creating energy efficiency in construction. In this test, two different percentages of concrete (0% of PET, 25% of PET) were used, and the thermal conductivity of concrete samples was measured. According to Fig. 10, the thermal conductivity of concrete decreased gradually with an increasing percentage of PET waste. Concrete thermal conductivity decreased inversely with the increase of PET in concrete. The thermal conductivity of 0% of PET was 15 W/mK and 25% of PET was 1.85W/mK. This means that 25% of PET has the lowest thermal conductivity and better thermal insulation. According to the results of previous studies [29, 30] when 25% of PET was added to concrete, thermal conductivity decreased to less than 1 W/mK. There were differences between the outcomes of this study and previous studies related to a number of factors, such as type of cement, shape, particle size of PET, and measuring device. The result of this test concluded that the use of PTE in concrete can solve the thermal conductivity problem in the summer and increase thermal insulation, thereby making waste management more beneficial.

V. CONCLUSION

Solid waste management (SWM) constitutes a major challenge in Kurdistan, Iraq, and it must be at the top of the policymakers' list of priorities. Search for solutions to this crisis or challenge. In addition to benefiting from academic research, Since everyone is affected by environmental pollution, protecting the environment is everyone's responsibility. This research is sustainable for building construction. Because of its high sound absorption and low thermal conductivity, plasticized concrete (PC) can be used to improve the life quality of habitats. Based on the above results and discussions, the following conclusions can be drawn:

1. It is possible to produce lightweight green concrete (GC) with wasted materials, such as Plastic waste (PW). i.e., productions of plasticized concrete (PC).
2. Mechanical properties of concrete such as compressive strength are found to decrease from 36.63 (Mpa) to 17.26 (Mpa) when adding 25% of PW. In the present study the average decrease in the compressive strength when added 25% PP is about 51% from normal concrete (NC).
3. Thermal conductivity of the concrete is decreased with adding PP by about 50% from NC when PW increases up to 25%. The thermal conductivity of PC decreases by 1.85 W.m-1 K-1 when PW increases up to 25%.
4. Plasticized Concrete (PC) is Light for handling. It is identified that the density of concrete decreases when the percentage of replacement of PW increases from 0% to 25%.
5. The intensity of sound (or Noise level) decreased gradually from 65.5(dB) to 43.3(dB) when the percentage of replacement of PP increases from 0% to 25%.
6. Ultrasonic pulse velocity of NC decreased gradually from 4.70 m/s to 3.56 m/s when the percentage of replacement of PP increases from 0% to 25%.
7. As we mentioned, this research is sustainable for building construction. It supports the environmental concern related to SWM. Since plastic exists in the world in a large number and non-biodegradable material so needs a thousand years to be decomposed and causes a serious problem to the environment. PW can be used in the construction industry and have advantage in many ways for the properties of the construction industry and economic benefits.
8. Because the thermal conductivity of the concrete can be reduced when PW is added to NC. Therefore, PC can be used efficiently or effectively in a variety of applications that require insolation. The need to generalize the use of environmental building codes. That, the use of (codes) environmental buildings is necessary for build of residential buildings, as well as the use of new materials (insulating bricks, PC, rubberized concrete, therm-stone, etc.) in which the thermal conduction factor is less than other local building materials.

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