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Evaluation and utilization of polymeric plastic wastes in concrete blocks

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ABSTRACT

There is however a dearth in the utilization of plastic pellets made of polyvinyl chloride (PVC) and polystyrene (PS) in concrete blocks. Hence, the current research investigated the exploitation of PVC and PS pellets in the production of concrete blocks. So, the PVC and PS were used as fine aggregates in concrete blocks. Two concrete block mixtures were prepared to evaluate their workability, bulk density, apparent porosity and compressive strength. The prepared samples of concrete mixture was substituted by 0, 5, 10, 15, 20 and 25 % of either PVC or PS. Results illustrated that PS absorbs more water than that of PS which absorbs less water. The workability of both PVC and PS concrete blocks improved and enhanced as the content of PVC and PS plastic wastes was increased. The compressive strengths of the PS concrete blocks were slightly higher than those of PVC at any content. This implied that the incorporation of PS plastic wastes can be a propitious solution to the plastic waste dilemma and demand for stronger concrete blocks.

Keywords: Cement, plastic wastes, blocks, density, porosity, strength.

1. INTRODUCTION

1.1. Scope of the problem

Population concurrently grows exponentially with the demand for food and infrastructure associated with plastic waste mismanagement and concrete consumption. However, there is a dearth in the utilization of plastic pellets using polyvinyl chloride (PVC) and polystyrene (PS) in concrete blocks. It is worth to mention that the growing of the exponential population has been produced ripple effects over thru decades. The preoccupation of this growth entails a growing number of problems in the demand and consumption of the fundamental needs of human beings, but not to mention the foods and the shelter, beside others. However, the processes underlying food production and materials for infrastructure as well as their preservation greatly contributed to a multifold and alarming increase in waste products.

Human beings always have been utilizing plastic materials in manufacturing, storing, and preserving foods. This seemed to be of a great catalyst to achieve such convenience. The benefits brought by the use of these plastics are stifled by its alarming effects on the environment. One of which is the staggering report on plastic debris in the ocean which has been recorded to be 5.25 T pieces already with a rate of 8 million trashes from 192 coastal countries [1-3]. The coastal countries are intensely contributed to plastic pollution globally. Some countries discarded about 125 000 plastic bags of daily which did not surprise science specialists who were aggregating to 1.88 million tons of plastic wastes yearly. The recent battle with plastic mismanagement urged various organizations and local government units to set several politics to put an end to this environmental problem. Some of them act through implementing politics in partnership with different companies and organizations [3-6].

A side from food, the exponential demand for shelter and infrastructure entails the rise in the demand for construction materials with sufficient fresh and strength parameters to withstand any topographical and environmental risks and disasters such as typhoons and earthquakes. Water as first and followed by concrete hollow blocks (CHB) are the top two most consumed substances on Earth. These materials are of a big demand in the sector of industry for infrastructural projects [5-7].

Innovations have been established by replacing the aggregates of different materials to improve the parameters of concrete hollow blocks as compressive strength, workability, mechanical properties and others. Generally, fresh and strength parameters of concrete increase almost linearly as the percentage of replacement increases. The studies have established the fact that replacing the constituents of concrete affects the fresh and strength parameters of concrete [1, 8-20].

Replacing fine aggregates with plastic waste materials abound in the scientific society to solve both the need for stronger concrete hollow blocks and solutions for recycling plastic wastes. The addition of fine aggregates to polypropylene pellets (PP) at the expense of fine aggregates is the main target of that study. However, there is a dearth of studies that maximize the use of other types of plastic materials like low-density polyethylene (LDPE), high-density polyethylene (HDPE), polyvinyl chloride (PVC), and polystyrene (PS) [14]. As the recommendation of the latter study, extensive investigation on the use of different types of plastic wastes aside from PP and measurement of other strength parameters should be further conducted. The present study characterized PVC and PS pellets as concrete hollow blocks reinforcement; determined the effects of varying percentage replacement of fine aggregate with PVC and PS pellets on the fresh and strength parameters of concrete hollow blocks such as workability and compressive strength; and compared the PVC- and PS-blended concrete hollow blocks fresh and strength parameters.

1.2. Objectives of the study

The essential goal of the present investigation is to study and evaluate the influence of the dry plastic wastes of PVC and PS on the physical and mechanical properties of the prepared concrete block samples containing it in terms of workability, density, porosity and compressive strength.

2. EXPERIMENTAL

2.1. Raw materials

Plastic wastes that were manufactured by polyvinyl chloride (PVC) and/or polystyrene (PS) were provided by a local plant, Egypt. These waste materials were fine ground, processed and prepared before mixing. The Ordinary Portland cement (OPC Type I- CEM I 42,5R) having the blaine surface area or fineness 3400 cm^2/g) as received was provided by a local supplier (El-Amrya cement factory, Alexandria, Egypt. At first, the pellets of PVC and PS were characterized before mixing as recommended in the cited literature [14]. The tap water is commonly used for mixing and curing with specific gravity of 1.00. The PVC sample is thermoplastic pellets that often used to make wire cable insulation were taken from a local plant that usually receives these ground residual wastes from several electronic companies. On the other side, PS sample was in the form of plastic cutlery wastes from the same plant. These cutleries were ground in a suitable grinding machine to achieve fine pellet size (Figure 1). These pellets were subjected to sieve analysis. Larger size of these pellets (> 4.75 mm) must be excluded because it may affect the strength of the tested samples [14]. These materials were characterized in terms of density and specific gravity using principles of Archimedes [14], bulk density [21], and absorption for 24 hours [22]. The used fluid in the characterization of PVC pellets was distilled water, while isopropyl alcohol was used for PS pellets due to the difference in specific gravity as shown in Table 1. The chemical analysis of the OPC as measured by X-ray florescence technique (XRF) is listed in Table 1, while its mineralogical constituent as calculated from Bogue equations is given in Table 2. The sand sample was brought from the desert of 6 October city, Giza, Egypt.

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(A) Polyvinyl chloride (PVC) **(B) Polystyrene (PS)**

Figure 1: Pellets of Polyvinyl chloride (A) and polystyrene samples (B).

Table 1 - Chemical analysis of the OPC, GbfS and PC raw materials, mass %.

Oxide / Material	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	MnO	SO_3	Na_2O	Ti_2O	K_2O	LOI
OPC	**20.12**	**4.25**	**1.29**	**63.13**	**1.53**	**0.36**	**2.54**	**0.55**	**0.19**	**0.30**	**2.64**

Table 2 - Mineralogical composition of the OPC and GbfS

Phase / Materials	C_3S	C_2S	C_3A	C_4AF
OPC	**65.78**	**8.67**	**8.24**	**11.71**

2.2. Preparation and methods

The concrete mixture was prepared from OPC, sand and aggregates. The plastic wastes of PVC and/or PS pellets were substituted at the expence of sand. So, The mixtures of the first group were containing PVC, whereas the second group was incorporated PS. The first was composed of concrete mixture and PVC as 100:0, 96:5, 90:10, 85:15, 80:20 and 75:25 having the symbols: V0, V1, V2, V3, V4 and V5, respectively. The second was composed of concrete mixture and PS as 100:0, 95:5, 90:10, 85:15, 80:20 and 75:25 having the symbols T0, T1, T2, T3, T4 and T5, respectively. The composition of the concrete blends of the first group is illustrated in Table 3, whereas that of the second group is shown in Table 4, respectively.

Table 3- Mix composition of the first group composed of Concrete mixture and PVC (PC).

	Group I (PC)					
Mix / Materials	**V0**	**V1**	**V2**	**V3**	**V4**	**V5**
Conc. Mix	**100**	**95**	**90**	**85**	**80**	**75**
PVC	**0**	**5**	**10**	**15**	**20**	**25**

Table 4-Mix composition of the second group composed from concrete mixture and PS (PS).

	Group II (PC)					
Mix / Materials	**T0**	**T1**	**T2**	**T3**	**T4**	**T5**
Conc. Mix	**100**	**95**	**90**	**85**	**80**	**75**
PS	**0**	**5**	**10**	**15**	**20**	**25**

The blending process of the various cement batches was firstly done in a porcelain ball mill using three balls for two hours to assure the complete homogeneity of all cement batches. The materials of cement and sand were mixed in the ratio of 1:3, while water to cement mix was 0.5 by volume. During mixing, the suggested water ratio was poured on the cement powder in the mixer gradually. Then, the mixer was operated for 5 minutes with a mean velocity of 10 rpm to reach the entire matching pastes. Before casting, the moulds were covered by a thin layer of oil to easily the removal of cement cubes from the moulds on de-moulding

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process. The prepared cement pastes were then moulded into stainless steel moulds of dimensions 4 x 8 x16 inches, and then vibrated manually for three minutes, and then on a mechanical vibrator for another three minutes to remove all air bubbles tapped inside the cement pastes. The moulds were completely casted with cement pastes and its surface was flatened with a suitable spatula [23-28]. After casting of samples, they were covered with a wet sheet during the first 24 hours to prevent moisture loss. The moulds were then placed in a humidity chabinit for 24 hours under 95 ± 1 relative humidity (RH), and room temperature (23 ± 1), demoulded in the next day. After complete drying, the samples of concrete blocks were subjected to bulk density, apparent porosity, and compressive strength.

The workability of concrete mixtures was carried out through slump test [29]. It determines the conformaty of fresh concrete before it hardens. It is performed to attain the workability of fresh concrete, and therefore, the ease with which concrete flows. Also, it can be used as an indicator of an improperly mixed batch. The bulk density (BD) and apparent porosity (AP) of the hardened concrete blocks [25-30] were calculated from the following equations:

B.D, (g/cm^3) = W1/(W1–W2) × 1 (1)

A.P, % = (W1 – W3)/(W1–W2) × 100 (2)

Where, W1, W2 and W3 are the saturated, suspended and dry weights, respectively. The compressive strength (CS) of the various hardened concrete blocks [31,32] was measured and calculated from the following relation:

CS = L (KN)/Sa (cm^2) KN/m^2 x 102 (Kg/cm^2)/10.2 (MPa) (3)

Where, L is the load taken, Sa is the surface area.

3. RESULTS AND DISCUSSIONS

3.1. Physical characteristics of PVC and PS

Plastic wastes were compared in terms of their physical properties as specific gravity, bulk density (g/cm^3), rate of absorption (%) and its behaviour in water. Table 5 and Figure 2 demonstrated the comparison between these waste raw materials. These values were used in mixing of the constituents of concrete blocks and are the basis for the justifications in the workability and compressive strength. As it is illustrated, the sand and PVC fine aggregates were sinking in the water, while PS fine aggregates were floating. Furthermore, the PVC has greater absorption ability than PS, i.e. for normal hydration, the concrete mixtures containing PS fine aggregates need water more than that of PVC fine aggregates [33-35]. Meanwhile, the PVC waste pellets sank in water. This in turn justified that whether the waste plastic pellet sinks or floats in water, it can be used as fine aggregate substitution for concrete structures [36,37].

Table 5- Physical properties of the used sand and plastic waste materials

Property Materials	Specific gravity	Bulk density, g/cm^3	Absorption, %	Behaviour in water
Sand	**2.47**	**2.47**	**1.34**	**Sink**
PVC	**1.39**	**1.411**	**0.931**	**Sink**
PS	**1.03**	**0.973**	**0.103**	**Float**

3.2. Workability

The workability of the various blended concrete structures as measured through slump test (mm) is shown in Figure 3. As it is clear, the workability increased as the amount of either PVC or PS plastic wastes increased in the concrete mixture. Moreover, the values of workability that obtained with PS are higher than those obtained with PVC. This principally attributed to the fact that the PS waste pellets required more water to produce suitable workability than that needed by PVC [14,33-35]. Accordingly, the workability of the blank recorded the lowest workability, while those containing 25 % of the two types of the plastic wastes achieved the highest [14,17,31,36,37]. However, the cement structures incorporating PS exhibited slump values higher than those containing PVC at all replaced quantities.

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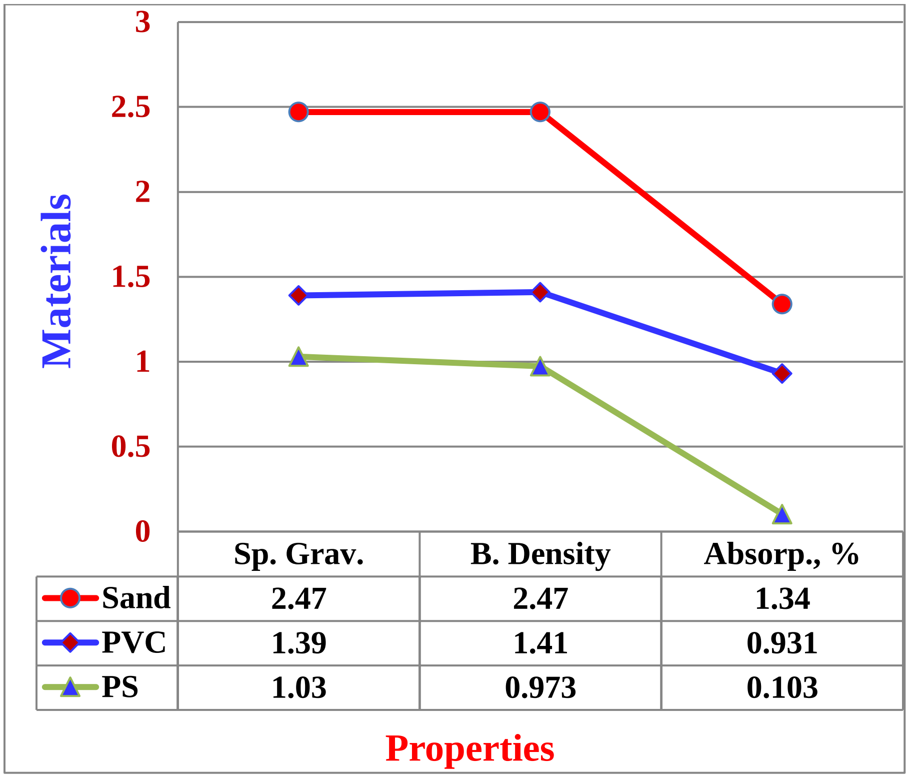

Figure 2- Physical properties of the used sand and plastic waste materials.

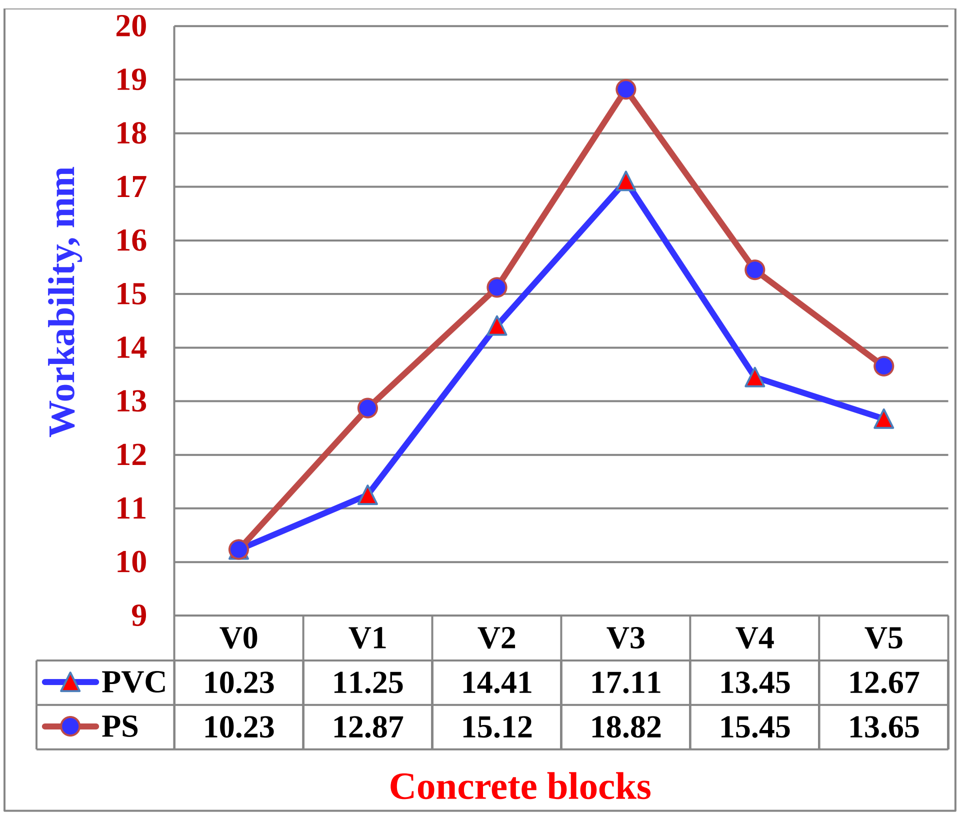

Figure 3-Workability of the various concrete structures with or without PVC and PS plastic wastes.

3.3. Bulk density and apparent porosity

The bulk density and the apparent porosity of the various blended concrete structures are represented as a function of concrete blocks in Figures 4 and 5, respectively. As it is shown, the apparent porosity of the concrete block samples decreased as the content

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of both PVC and PS increased, while the bulk density increased. This could be taken place only up to 25 %, of the two types of plastic wastes (V3 and T3). With further increase of PVC or PS contents, the apparent porosity started to increase, while the bulk density diminished (V4, V5 and T4, T5). Moreover, the apparent porosity of concrete blocks containing PS is lower than those containing PVC plastic wastes whereas the bulk density is higher. This occurred with all quantities of either PS or PVC. This may be due to the greater rate of absorption of PS than PVC plastic wastes, which allowed to improve and enhance the rate of hydration [13,17,20,37]. So, these concrete mixtures can be utilized in many massive structures like dams, bridge piers and even canals [38,39].

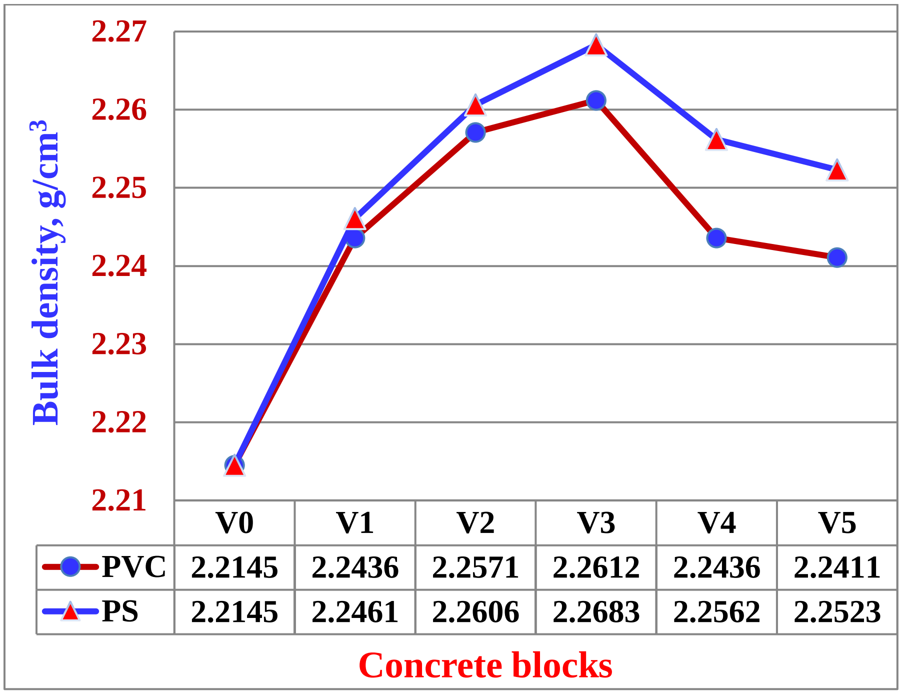

Figure 4-Bulk density of concrete blocks with and without PVC and PS plastic wastes

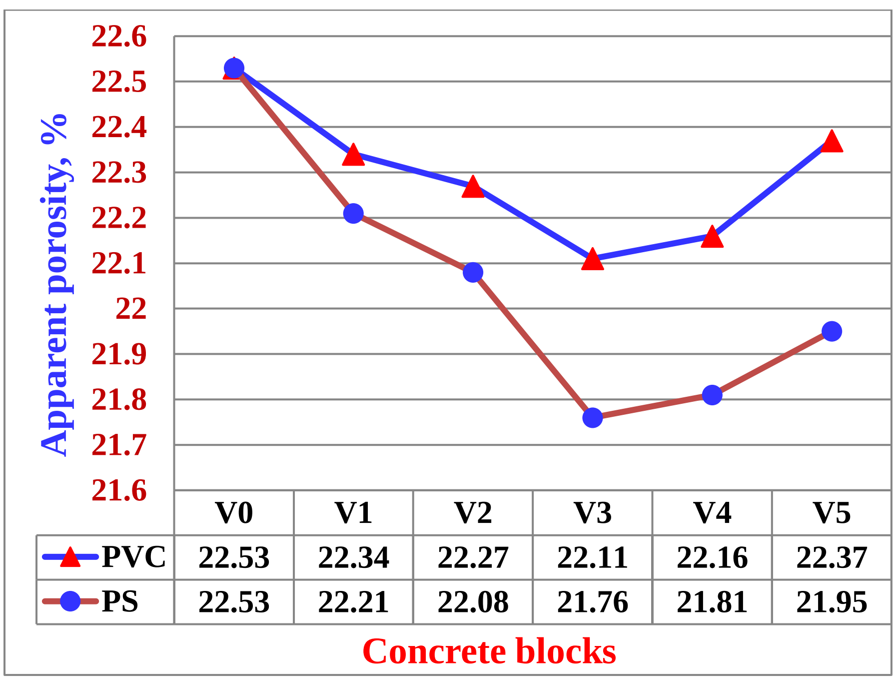

Figure 5-Apparent porosity of concrete blocks with and without PVC and PS plastic wastes.

3.4. Compressive strength

The results of compressive strength of the various blended concrete blocks are graphically plotted as a function of concrete blocks in Figure 6. The compressive strength of the blank is 4.14 MPa. This value was slightly increased with the blending the concrete

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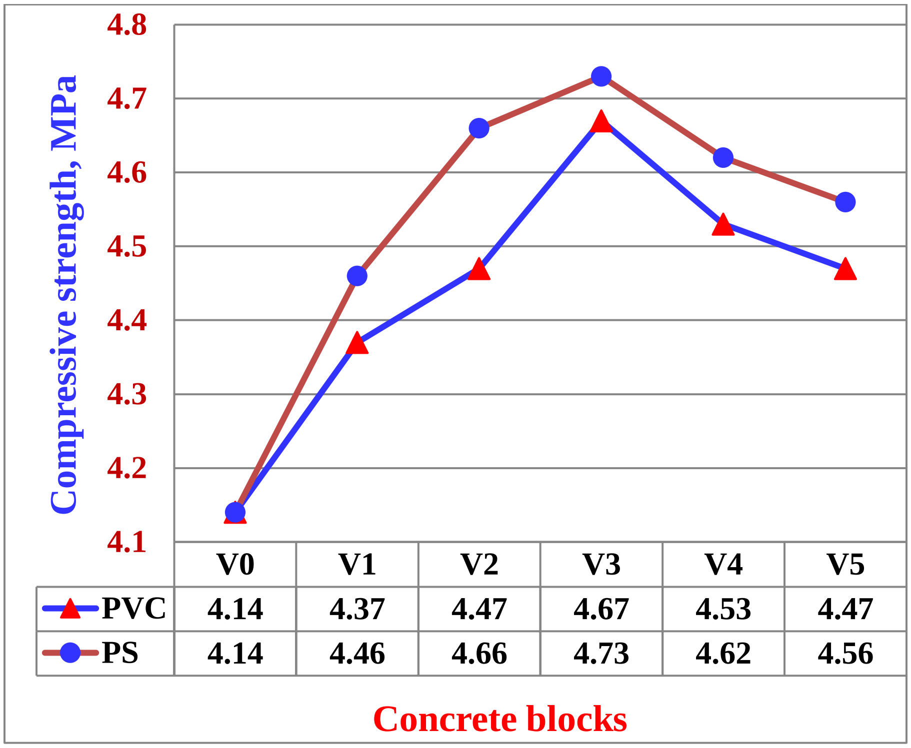
mixture with both PVC or PS plastic wastes, but only up to 25 % of either PVC or PS (V3 and T3), and then declined with further increase of either. Furthermore, the compressive strength of concrete mixtures incorporating PS is slightly higher than those containing PVC. Also, the compressive strength of both groups achieved the same trend, i.e. behaved like others. The increase of compressive strength is essentially contributed to that the PS waste pellets diminish the porosity of the tested samples more than in case of PVC, in addition that the PS improved the hydration of concrete mixture more than that of PVC [13,14,23,24]. Meanwhile, Batch T3containing 25 % PS plastic pellets and Batch V3 incorporating 25% PVC plastic pellets attained the highest values of compressive strength as the experimental data demonstrated. These data and notifications were confirmed in several studies [13,17,20,39-41]. This trend was attributed to the lower absorption of the pellets in general resulting in a greater amount of water suitable for the hydration of the concrete mixture. However, the concrete blocks with PS plastic pellets are better than those with PVC.



	V0	V1	V2	V3	V4	V5
PVC	4.14	4.37	4.47	4.67	4.53	4.47
PS	4.14	4.46	4.66	4.73	4.62	4.56

Figure 6 - Compressive strength of concrete blocks with and without PVC and PS plastic wastes.

4. CONCLUSIONS

The following overall conclusions could be obtained:-

1. Due to density and specific gravity properties, the PVC plastic waste pellets are floating when placed in water, while PS plastic waste pellets are sinking. Also, the PVC plastic waste pellets have greater absorption ability than PS plastic waste pellets, where both were lower than those of the used sand. The PVC plastic waste pellets absorb water more than PS plastic pellets, i.e. if the pellets are mixed in two different concrete mixtures, there will be more water available in the PS mixture than in the PVC mixture for hydration.
2. The workability due to slump test of fresh concrete mixtures increased as the content of both PVC and PS plastic waste pellets increased. The slump values of the prepared concrete blocks from both PVC and PS plastic waste pellets are seemed to be suitable for roads and some massive concrete blocks for dams, bridge and canal locks or piers.
3. The compressive strength of the prepared concrete blocks enhanced with the increase of PVC or PS plastic waste contents, only up to 25 %, but then decreased with further increase of it. Furthermore, the compressive strength of concrete blocks incorporating PS plastic wastes was higher than those containing PVC plastic waste pellets at any amount. It is good mention that this is a propitious solution to solve problems of plastic waste management of PS type of plastic and the demand for stronger concrete blocks in the infrastructure industry.

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4. Further investigations must be done to identify whether greater quantities from PVC or PS plastic wastes more than 25 % can be considered. In addition, other forms and grain sizes as fibres or flakes of these plastic waste pellets or any other plastic wastes can be exploited.

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Conflict of Interest

The author declares that there are no conflicts of interests.

Data and materials availability

All data associated with this study are present in the paper.

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