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# Influence of Incorporating PVC Waste on the Mechanical Properties of Cement Mortar

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**Keywords:**
Cement mortar
PVC waste
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**ABSTRACT**

Currently, recycling of industrial wastes to reduce the environmental impact is the major concerns of researchers. Polyvinyl chloride (PVC) is one of the waste materials worldwide, with considerable impacts on environmental. Recycling PVC wastes in the concrete or mortar industry is one of the adopted ways to decrease such impact. The purpose of this paper is the reuse of PVC waste deriving from the workshops manufactured doors and windows which made of PVC material. The waste of polyvinyl chloride was collected from one of the factories located in AL-Khoms, then the waste was sieved, the sample that passed through Sieve No.4 and retained on sieve No.10 was taken. The PVC waste proportions of (0.06 ، 0.08 ، 0.1) by weight of cement was added to the mix mortar. The tests carried out during this study were; air content of fresh cement mortar, flow table, dry density of hardened cement mortar, flexural and compression, free shrinkage and finally ultrasound pulse velocity. The results obtained showed a significant improvement in the sound insulation and a decrease in the dry density of the mortar. While the compressive and flexural strength results were slightly lower compared to the standard mortar. In addition, a decrease in the values of flow, free shrinkage and air content was observed with an increase in the PVC content. Nevertheless, the mortar obtained contributes to the conservation of natural resources and maintains the mechanical properties of the cement mortar in structural applications.

# تأثير إضافة مخلفات البولي فينيل كلورايد على الخواص الميكانيكية للمونة الاسمنتية

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**الكلمات المفتاحية:**
المونة الاسمنتية
مخلفات مادة البولي فينيل كلورايد
الخواص الميكانيكية

**الملخص**

يُعد إعادة تدوير النفايات الصناعية للحد من الأثر البيئي الشغل الشاغل للباحثين في الوقت الحالي. البولي فينيل كلوريد (PVC) هو أحد مواد النفايات الصناعية المنتشرة في جميع أنحاء العالم، وله آثار كبيرة على البيئة. و تُعد عملية إعادة تدوير نفايات PVC في صناعة الخرسانة أو المونة إحدى الطرق المعتمدة لتقليل هذه التأثيرات. الهدف من هذه الورقة هو إعادة استخدام البولي فينيل كلوريد (PVC) الناتج عن نفايات ورش تصنيع الأبواب والنوافذ المصنوعة من مادة PVC. حيث تم جمع مخلفات مادة البولي فينيل كلورايد من أحد المصانع الموجودة بمدينة الخمس, من ثم نخلت بحيث تم استخدام النشارة المارة من المنخل رقم 4 و المتبقية على المنخل رقم 10. إضافة مخلفات البولي فينيل كلوريد الى المونة الاسمنتية كانت بنسب (0.06، 0.08، 0.1) من وزن الاسمنت المكون للعجينة الاسمنتية. و الاختبارات التي أُجريت خلال هذه الدراسة: الهواء المحبوس و الانسياب و الكثافة الجافة و اختباري الانحناء و اختبار الضغط و الانكماش الحر و اخيرا اختبار سرعة الموجات فوق الصوتية. النتائج المتحصل عليها بينت وجود تحسن ملحوظ في العزل الصوتي و انخفاض في الكثافة الجافة للمونة المتصلبة. بينما كانت مقاومة الضغط و الانحناء منخفضة قليلا مقارنة بالعينة القياسية. إضافة الى ذلك لوحظ انخفاض في مقدار الانكماش الحر والانسياب و نسبة الهواء المحبوس بزيادة نسبة مخلفات البولي فينيل كلورايد. رغم ذلك، المونة المتحصل عليها يتوقع أن تساهم في الحفاظ على الموارد الطبيعية مع الابقاء على الخواص الميكانيكية ضمن التطبيقات الانشائية للمونة الاسمنتية.

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## Introduction

Since concrete of all types became the most common material in the field of construction, the trend has increased to look for alternatives concrete components. Therefore, producing a concrete compatible with sustainable development, distinctive properties such as sound and thermal conductivity and lightness. Among the alternative materials used in concrete are industrial and agricultural wastes, such as wastes from the rubber, glass, plastic, paper industries, blast furnace slags, RHA and palm oil fuel ash [1]. Previous research has demonstrated that adding industrial waste as fiber to concrete yields significant benefits, including reducing shrinkage, enhancing tensile and fatigue strength, and improving impact resistance [2,3]. Recycling such wastes as constituent materials for concrete is a viable solution not only to the problem of pollution, but also for the problems of economical design of concrete structures [4,5]. The use of such waste as building materials will greatly contribute not only to reducing environmental problems, but also lead to the development of innovative and cost-effective building materials and improved construction techniques to meet strict requirements, including the disposal of plastic waste. Due to rapid industrialization, the production of plastic waste has increased exponentially in recent years, posing challenges in terms of its disposal [6]. Plastic pollution refers to the accumulation of plastic products in the environment, leading to adverse effects on land, waterways, and oceans. According to the researchers, plastic is a non-biodegradable material that can persist on Earth for up to 4500 years without undergoing degradation [7].

Over the past five decades, polyvinyl chloride (PVC) has emerged as the primary construction material. Global vinyl production now totals over 35 million tons per year, and is estimated to reach much higher over the next few years, the majority of which is directed to building applications, furnishings, and electronics [8]. The widely global utilization of PVC generally results in a great quantity of waste. Every day, these wastes are rising, and are disposed in landfills, but this route actually is not favourable in many countries because of the reduction in existing landfilling areas and potential environmental hazards. Neither of the disposal methods is optimal for waste disposal, and both contribute to environmental pollution on land and in the air.

The risk of PVC waste is greater than the others like polyethylene terephthalate (PET) for the reason that chlorine is present in its compounds, which is around 57% of PVC chemical structure [9,10]. Burning of PVC waste is not a solution to consume such waste because this process will dismiss dangerous chemical gases into the air such as dioxin compounds and hydrogen chloride [11]. In no way can this material be converted into an environmentally friendly product, even after processing. In addition, recycling the waste of this material to return it as a raw material does not have a significant economic return. The potentiality of recycling the PVC wastes is therefore of genuine interest. In a country like Libya, no house or institution is devoid of the presence of such a material, and is no way to prevent the use of this material, especially in the manufacture of doors and windows. Therefore there is no manner to minimize the residual of this material in the workshops of the manufacture of doors and windows. This social awareness is making the development in new methods of recycling PVC wastes an advantage. Replacing sand and gravel by recycled PVC waste in concrete manufacturing can be one of the environmentally friendly methods because there is a major demand for structures worldwide, especially in developing economies [7].

The main objectives behind this study to find out the effect PVC waste on the most engineering properties of mortar using the local materials.

## 2. Experimental program

### 2.1 Materials

In this study, ordinary Portland cement (OPC) was utilized, adhering to the specifications outlined in the standard LSS-340-09 [12]. The cement was sourced from the El-Mergib plant situated in Al-Khums. Detailed information regarding the physical properties and chemical composition of the cement can be found in Table 1.

**Table1: Chemical composition and Physical properties of used cement.**

| Chemical comp. (%) | | Physical properties | |
|---|---|---|---|
| Component | Value | Property | Value |
| $SiO_2$ | 22.01 | Sp. Gravity | 3.23 |
| $Al_2O_3$ | 2.67 | Sp. Sur. Area ($cm^2/g$) | 2678 |
| $Fe_2O_3$ | 4.4 | Ini. Sit. Time (h:min) | 2:25 |
| CaO | 61.8 | Fin. Sit. Time (h:min) | 3:55 |
| MgO | 1.56 | Soundness (mm) | 1.5 |
| $Na_2O$ | 1.86 | Comp. St. at 3 d (MPa) | 26 |
| $K_2O$ | 0.23 | Comp. St. at 28 d (MPa) | 44 |
| $SO_3$ | 1.03 | | |
| Free lime | 2.23 | | |
| LOI | 1.83 | | |

Natural sand with maximum size of 1.2 mm was used as a fine aggregate in accordance with standard BSI 812 – 1995 [13], which collected from quarries of Zlitan. The fine sand displays a fineness modulus of 2.8, a specific gravity of 2.62, and a water absorption ratio of 0.83%.

Tab water is used obtained from the water desalination plant in city of AL-Khoms.

The PVC waste utilized in this study was sourced from PVC operation workshops situated in the city of Al-Khums, considering its purity from impurities. The size of PVC waste was between 5 mm and 2 mm. The PVC waste used is illustrated in Figure 1.

**Fig. 1:** View of PVC waste.

### 2.2 Preparation of mortar test specimens

Four mixes of cement mortar were prepared, all mixes were varied in the amount of PVC waste, except for the control mix, which was free. The PVC waste proportions of (0.06 ، 0.08 ، 0.1) by weight of cement were added to the mix. These proportions were chosen based on the flow table test, which gave the best results. The complete details of the

PVC waste ratios is presented in Table 2. Immediately after the completion of the mixing stage, the tests on fresh mixes were carried out, which is to determine the air content and flow. After that the specimens were allowed to dry for 24 hrs and then soaked in water for specified period test, with the exception of the shrinkage specimens, which were tested after 24 ± 1 hours of drying.

**Table2:Mix proportions of cement mortar mixtures.**

| Mix ID | Cement C/C | Water W/C | Sand S/C | PVC waste PVC/C |
|---|---|---|---|---|
| Control | 1 | 0.4 | 0.8 | 0 |
| Mix-1 | 1 | 0.4 | 0.8 | 0.06 |
| Mix-2 | 1 | 0.4 | 0.8 | 0.08 |
| Mix-3 | 1 | 0.4 | 0.8 | 0.1 |

**2.3 Test methods**

For determining the quality of mortar concerning its consistency, cohesiveness and the proneness to segregation, the flow table test was conducted. The test was carried out according to Standard ASTM C230/C230M-15 [14].

The air content test was conducted to assess the proportion of air voids present in the mushy mortar that contained PVC waste. This test was conducted in accordance with Standard ASTM C185 –15 [15].

Dry density test was accomplished at the age of 28 days, following by ASTM C642 [16]. Cement mortars were made in 70.5 mm size cubes molds. The specimens were hardened and heated to between at 60 ˚C in oven for 24 h and then cooled. The process was continued until any successive values had a mass difference between them that was less than 0.5%. After that, the specimens were weighed every 24 hrs for at least 48 hrs while being absorbed water at room temperature. This mass was recorded as the wet mass, then the specimens were suspended and weighed in water after 5 hrs of immersion in boiling water, followed by at least 14 hrs of cooling and weighing in air. The following formula were used to determine the density.

$$\text{Dry density} = \frac{A}{C - D} \qquad (1)$$

where (**A**) is the dry weight of the sample, (**C**) is the weight of wet specimen in air after boiling, (**D**) is the weight of wet sample floating in water after boiling.

The test procedures for determining the compressive strength of cement mortar were conducted following the guidelines outlined in the ASTM C109/C109M [17] at 3, 7 and 28 days. The adopted geometry for the compressive strength specimens of 70.6 mm size cubes. The test was performed under a load rate of approximately 1.8 KN/min. A universal testing machine (Form + Test Prufsystem Formmessplatz Mega 10-300-10) located in the concrete crosstie plant in city of Al-Khums city was used for this test.

Flexural strength tests were carried out in accordance with Standard ASTM C348-14 [18]. The flexural strength of the beams with size of 40 mm × 40 mm × 160 mm at 7 and 28 days were determined. The universal testing machine used for the compressive strength tests was also utilized for this purpose.

The free shrinkage of mortar specimens was tested according to Stranded ASTM C157/C157M-08 [19]. The size of the specimen was 40 mm × 40 mm × 160 mm (Fig, 2). To measure shrinkage strains along the length of the specimens, two pairs of stainless steel discs of gauge length (**$L_0$**) 100 mm were fixed at both ends of the specimens, so that there is a pair of every two opposite surfaces. A digital strain gauge with a precision of $10^{-3}$ mm was used (Fig. 3). The specimens were dried at room temperature for 56 days. Subsequent shrinkage readings were taken after 3, 5, 10, 15, 20, 25, 30, 35, 40, 45, 50 and 56 days. The initial length was recorded as (**$L_1$**) and the subsequent length (**L**) were measured periodically. The drying shrinkage is expressed by the following [20]:

$$\text{Free shrinkage } (\varepsilon_f) = \left(\frac{L_1 - L}{L_0}\right) \times 100 \qquad (2)$$

**Fig. 2:** Free shrinkage specimens.

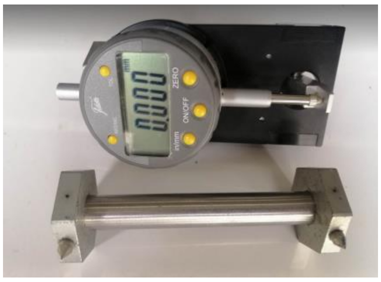

**Fig. 3:** Digital strain gauge.

The Ultrasonic Pulse Velocity (UPV) test was employed to evaluate the impact of incorporating PVC waste on the acoustic properties of cement mortar, specifically focusing on sound transmission. The calculation of the ultrasonic pulse velocity average was taken at 7 and 28 days. This test was carried out according to Standard ASTM C597-09 [21].

**3. Experimental results and discussion**

**3.1 Flow**

The results of the flow table test with PVC additives mortar mixtures are presented in Figure 4.

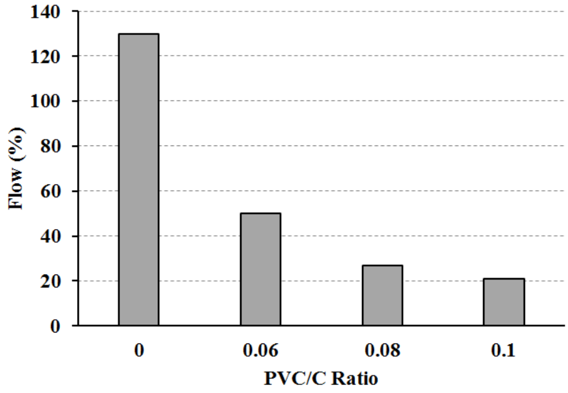


**Fig. 4:** Flow table test results of mortars with different proportions of PVC waste additive.

In general, mixes produced with PVC experienced a loss of flow. The results indicate a sharp reduction in fluidity at the PVC/C ratio of 0.1 and 0.08, but less reduction at 0.06. With a PVC/C ratio of 0.06, 0.08, and 0.1 , the cement mortar shows flow values of 50%, 27%, and 21% respectively, i.e. when the content is increased from 0.06 to 0.1, the flow is reduced by 61% to 83 %, meaning the flow is decreased as the content of PVC waste is increased.

This can be explained by the fact that an increase in the amount of PVC waste in the cement mortar is accompanied by an increase in the resulting friction between the components of the mixture due to the sharp edges angular particle size of PVC waste. In addition, the reason may be that the PVC waste can consume a part of free cement paste, and the friction between the particles increases with the increase of PVC content. Generally, the existence of PVC waste hinders the flow of cement paste leading to a reduction in fluidity. However, Similar response to the addition of PVC waste has been achieved by different study [22].

### 3.2 Dry density

Test results of hardened mortar dry density with PVC waste ratio at the age of 28 days compared to stranded mix are shown in Figure 5. Test data show a clear reduction in mortar dry density when PVC waste is increased. In comparison to the dry density of standard mortar, which was 2.78 g/cm$^3$, the maximum reduction in dry density is occurred at PVC/C ratio of 0.06 followed by 0.08 and then 0.1, where they were 2.64 g/cm$^3$, 2.53 g/cm$^3$ and 2.51 g/cm$^3$ respectively.

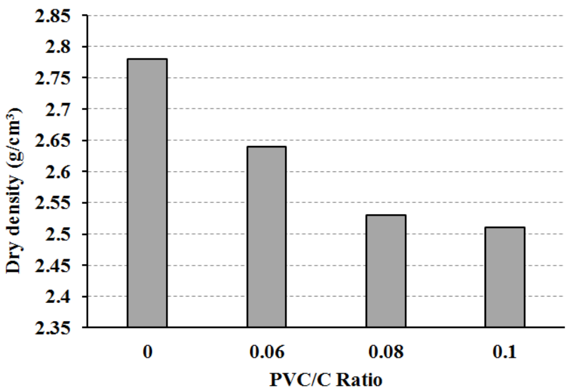


**Fig. 5:** The relationship between PVC waste content and variation in dry density.

The drooping in density is attributed to the lower density of PVC waste as compared with density of the solid components of mortar such as sand, i.e. the reduction of mortar dry density take place is because of adding a lightweight plastic one. One can find that replacing sand with PVC waste will lead to the density loss about two times that when sand is replaced with PVC waste [23]. The reason might also as a result of the difference in the mix proportions due to PVC was added by weight not by a volume, as a result of low specific gravity of PVC waste when compared to solid other components of mortar [24]. However, according to ACI 213R-14 [25], the oven dry densities of structural lightweight concrete are between 1.7-1.9 g/cm$^3$, therefore theses mixes are not classified as structural lightweight mortar. It can be seen that this decrease in intensity matches what has been reported by the past investigations either on concrete or mortar [9,22].

### 3.3 Air content

The air content is closely related to the presence of voids within the fresh mortar mix. In this study it was observed that the air content of cement mortar was significantly affected by the addition of PVC waste. As a general trend, the percentage of air content increases with increased PVC waste in the mortar mixes (Fig.6). However, the air content increased by 4%, 20% and 30% when PVC waste was added to the cement mortar at PVC/C ratio of 0.06, 0.08 and 0.1, respectively. Such result allows justifying the decrease in density of the mortars. This behavior may be explained by the fact that the PVC fibers increases total porosity by affecting the air content of mixtures, and may contribute significantly to the formation of air voids in the fresh mortar containing the PVC waste resulting in lower density and thermal conductivity. In addition, the presence of PVC waste causes an increase in friction between the particles, and as the result higher air content with the increase in the PVC/C ratio [26].

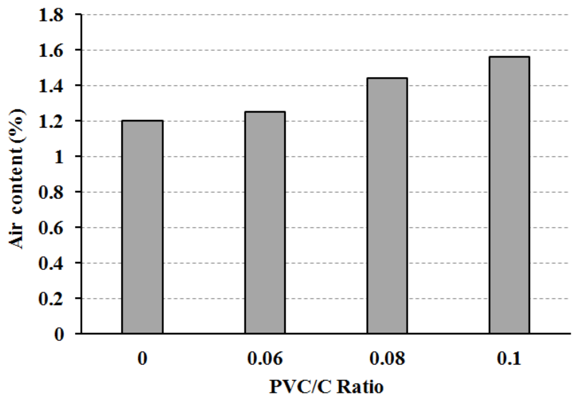


**Fig. 6:** Air content results of mortars with different PVC/C ratios.

As indicated above, the existence of PVC waste hinders the flow of cement paste leading to a reduction in fluidity, and this may be causes more bubbles to be entrained in, resulting in a higher air content [27].

### 3.4 Compressive strength

Figure 7 illustrates the impact of incorporating PVC waste fibers on the compressive strength of mortars at 3, 7, and 28 days. The test results indicate that the inclusion of PVC waste leads to a reduction in compressive strength across all age intervals. After 3 days , for PVC/C ratios of 0.06, 0.08 and 0.1, the compressive strengths were 35%, 51% and 53% lower, respectively, than that of the standard mortar, and after

7 days, the percentage was decreased by 28%, 34% and 44%, respectively. Whereas, at 28 days, compressive strength reduced by 25%, 32% and 37%, respectively.

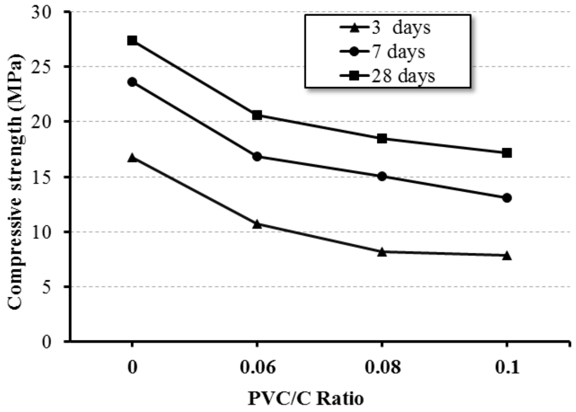


**Fig. 7:** Compressive strength test results of mortars at each curing period.

The significant decrease in compressive strength can be explained by the following reasons: (a) Cracks were initiated quickly around the PVC fiber due to the modulus mis-match because the PVC fiber have a lower elastic modulus than the surrounding cement paste. (b) The bond between PVC fiber and cement paste being less strong than the bond between natural sand and cement paste. (c) The rough texture of the PVC fiber led to a reduction in the level of packing of the mortar [10]. (d) A possible increase in matrix porosity, which would decrease the density and thus the compressive strength [28]. The obtained results align well with the research conducted by Merlo et al., where they observed a decrease in compressive strength due to inadequate bonding between PVC waste and the matrix [29].

According to standard ASTM C330-14 [30], the compressive strength of a structural lightweight concrete at 28 days should be higher than 17 MPa. The study revealed that the compressive strength of the mortar samples with the highest PVC/C ratio (0.1) exceeded 17 MPa, i.e. it complied with the above definition in terms of compressive strength.

### 3.5 Flexural strength

The flexural test assesses the tensile strength of mortar in an indirect manner. The results of flexural tensile strength test are presented in figure 8. It clearly exhibits that flexural strength of mortars increases as the curing time increases for all the specimens. These results of the study show that the flexural strength of mortars contained PVC waste decrease with increase the PVC waste. It is noticed that the mortars with PVC waste demonstrates low flexural strength in comparison to stranded mix. At PVC/C of 0.06 the flexural strength is 31 % and 10 % less than control mix at 7 and 28 days of curing respectively. At PVC/C of 0.1 the flexural strength is 20 % and 24 % less than the control specimen at 7 and 28 days of curing.

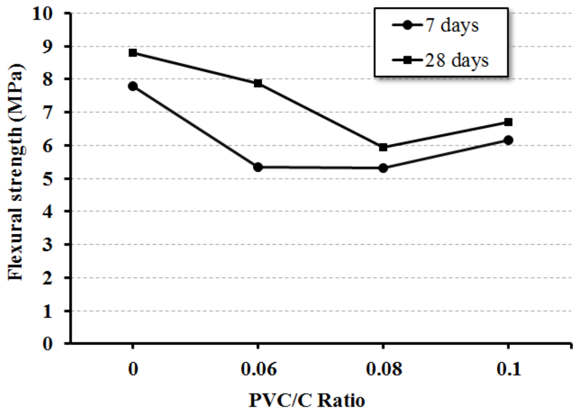


**Fig. 8:** Flexural strength test results of mortars at each curing period.

Similarly to the effect observed on compressive strength, the flexural strength of the concrete also exhibits a consistent decrease as the PVC content increases. These findings align with the results reported by Hussein et al., who conducted a study involving the partial replacement of sand with PVC waste. [24].

This phenomenon can be attributed to a decrease in the adhesive force between the surface of the PVC waste and the cement paste. This type of waste may be as a result of fibro-form of fine PVC waste, which works as fibers in solid by increasing crack level of resistance of the composite and the ability of materials to resist forces after the mortar matrix has cracked [24]. However, the mortars produced by adding PVC/C of 0.1 ,the strength is still permissible for using in plain construction applications.

### 3.6 Ultrasonic pulse velocity

Ultrasonic pulse velocities results of studied mortars at 7 and 28 days are shown in Figure 9. It is worth noticing that the result of UPV test showed that the values of mortars decreased as the amount of PVC waste in the mixture increased. At the age of 7 days, the percentage decrease in the ultrasound velocity value of mortars containing PVC/C ratio of 0.06, 0.08 and 0.1 were 11 %, 12% and 14% respectively. While, the percentages were decreased by 12 %, 16% and 17% respectively, at age of 28 days.

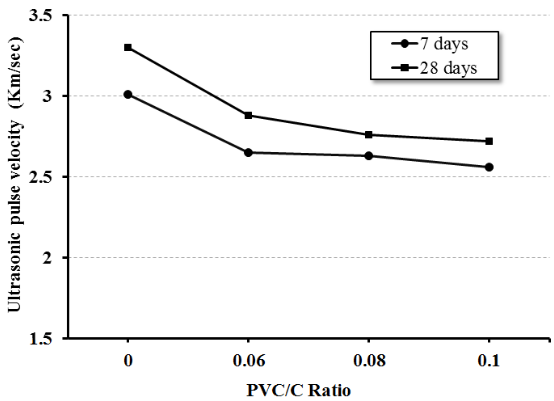


**Fig. 9:** Ultrasonic pulse velocity test results of mortars at each curing period.

As mentioned earlier, the inclusion of PVC waste directly impacts the porosity of the concrete. The presence of cavities formed by PVC fibers within the concrete results in the attenuation of ultrasonic waves due to changes in acoustic impedance. Moreover, since ultrasonic pulse velocity is influenced by the elastic properties and volumetric concentrations of the components, the addition of PVC waste would generally lead to a decrease in ultrasonic pulse velocity [31].

There exists a direct correlation between compressive strength and ultrasonic pulse velocity (UPV), where higher UPV values are typically associated with increased compressive strength. This behavior has been proven by this study. The pulse velocity depends on the elastic properties of the medium, as well as on the components that form the concrete. So, an estimation of the compressive strength can be predicted from the ultrasonic velocity. However; similar to the case of compressive strength, there is a continuous reduction in the ultrasonic pulse velocity values with increasing PVC content. Nevertheless, according to classification of concrete quality ratings based on UPV test BS: 1881: Part 203, the obtained results can be considered among the doubtful [32]. These results are in congruous with those of prior research carried out on the impact of incorporating PVC waste as a partial substitute for traditional aggregates in concrete. [9]. However, the results provided by this test indicated that mortars less sound conductivity could be manufactured by adding PVC waste to the cement mortar.

### 3.7 Free shrinkage

The average free shrinkage strains for periods of 3, 5, 10, 15, 20, 25, 30, 35, 40, 45, 50 and 56 days are illustrated in Figure 10. Evidently the free shrinkage rate is reduced gradually with elapsed time for all mortars.

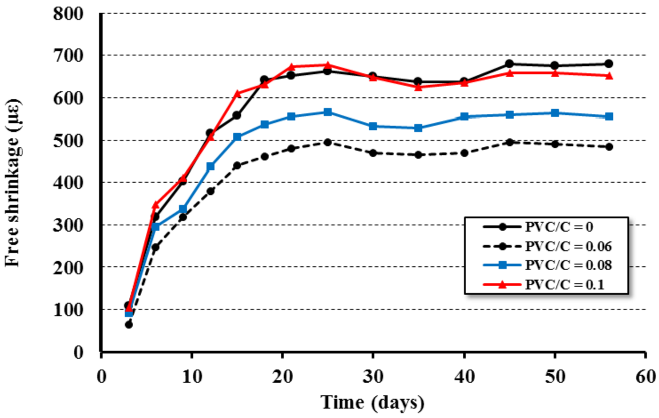


**Fig. 10**: Free shrinkage of mortar produced versus time.

Generally, by following the free shrinkage strain charts pattern, for all periods, it was observed that the standard mortar showed a higher shrinkage than that containing PVC/C of 0.06 and 0.08, while the results were almost converged with those containing PVC/C of 0.1. However, at a period of 56 days, the mortars containing PVC/C ratio of 0.06, 0.08 and 0.1 showed a decrease in free shrinkage by 28%, 17% and 3% respectively, compared to the standard mortar. It is expected that if the PVC/C ratio exceeds 0.1, this will lead to an increase in the free shrinkage by a value higher than standard mortar. Within the limits and variables of this study, this results agreed with the findings of Soroushian et al. who suggested that the shrinkage crack of concrete could be controlled by the introduction of plastic flakes [33]. In addition, the results was found to be in line to the published literature conducted by Kou et al. where they reported a decreasing trend of drying shrinkage with an increasing content of plastic and they justified this result considering that plastic particles do not absorb water and do not shrink, while sand actually does [9].

The shrinkage happens because of the capillary tensile force that is generated when water is lost from the mortar matrix. The stress due to such capillary tension is governed by the pore volume and size of the pore structure of the mortar. It can be presumed that PVC waste is impermeable and does not absorb water and does not shrink compared to sand, thus reducing the overall shrinkage of the mortar. [9].

As for the reason of the increase in the free shrinkage of the mix contained PVC/C of 0.1 with compared to that containing the lowest amount, may be due to the increase in air voids by increasing the amount of PVC content as previously indicated. The previous studies showed a significant increase in shrinkage strains of concretes with increasing content of air voids [34].

### 4. Conclusions

Based on results of this study and the analyses carried out it could be noticed the following conclusions:

- The addition of PVC waste resulted in a decrease in the flow of the mortar, with the lowest fluidity observed in the specimens with the highest PVC/C ratio. The mortar containing a PVC/C ratio of 0.1 exhibited an 83% reduction in flow, indicating a significant decrease in its fluidity.
- Significant decreases in the dry density are evident when PVC waste is incorporated into the mixes. The highest reduction in dry density, amounting to approximately 10%, was observed at a PVC/C ratio of 0.1. Compared with the standard mortar, this indicates the possibility of obtaining lighter weight mortar by adding PVC waste.
- It was seen that the addition of the PVC waste in the cement mortar mix leads to the increase in the air content. The increase in the percentage of air content was by 30% at the highest amount of addition. Such result allows justifying the decrease in density in the hardened mortars. This result may permits obtaining a mortar with less thermal and acoustic conductivity.
- At all ages, the compressive and flexural strengths decrease with PVC waste content in the mortars. A diminish in compressive of 37% for mortar containing PVC/C ratio of 0.1 is observed after 28 days, and attain 24% in flexural strength for the same mortar. However, at 28 days, both strengths of mixture containing the highest amount of PVC waste are considered reasonable for various construction applications.
- The UPV followed a similar trend as the compressive and flexural test results, with a decrease in values as the amount of PVC waste increased. However, this decline suggests a reduced potential for

sound transmission through structural elements constructed using mortars that incorporate PVC waste.

- At all periods, the free shrinkage of the mortars containing PVC/C of 0.06 and 0.08 were less than the standard mortar. While the results were almost converged with those containing PVC/C of 0.1, and still acceptable for several use of structural applications.

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