



Effect of Recycled PVC as a Partial Replacement of Fine and Coarse Aggregate on Some Concrete Properties

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ABSTRACT

Plastic is the highest used material in the world. The main problem is after the use this material, where their accumulation poses environmental problems due to no biodegradable. Recently, researchers have concerned with the reuse of plastic waste materials in the construction. In this paper, an experimental study on the recycled PVC as a partial fine and coarse aggregate replacement in concrete. Used PVC pipes was grained to different sizes and added to concrete mix. Replacement ratio of 10, 20 and 30% as well as reference mixes have conducted. The resultant of concrete properties such as workability, compressive strength, and Ultrasonic Pulse Velocity of the PVC concrete were discussed. In general, adding less than 10% of recycled PVC to concrete gives acceptable results of concrete properties. Increasing the percentage of PVC replacement in concrete by more than 10% is counterproductive as it reduces density, compressive strength, and durability. The lower mechanical strength of concrete may attribute to the weak of Interfacial Transition Zone (ITZ) between cement paste and PVC aggregates.

Keywords:

PVC Concrete
Recycled PVC
aggregate.

PVC replacement ratio.

PVC concrete properties.

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1 INTRODUCTION

The plastic products are commonly used in most fields, especially in industry, agriculture, and constructions. Due to ease of design, manufacture, and cheaper cost, plastics have been used increasingly in a large range of products [1]. More

than 275 million metric tons (MT) of plastic waste were generated in 2010 in 192 coastal countries, and up to 12.7 million metric tons may be dumped in the ocean [2]. The plastic production has grown to 348 MT in 2017 [3]. In 2018, a pilot study of six associations and organizations concerned in the plastics was found only 30 MT of this quantity has been produced from recycled raw materials and 360 MT was raw materials [4]. Although of considerable amounts of plastic production, only about 30% of the waste presents are recycled while its quarter goes to landfill, and the rest for energy recovery [5]. After 12 years, the recycled plastic waste amount was doubled from 2006 to 2018. The common type of the plastic use in construction is Polyvinyl chloride (PVC). In 1835, Victor Regnault was the first discoverer of PVC and developed manufacturing processes, after that by professor Fritz Klatte in 1912 [3]. The PVC presents 10 % of polymer types in 2016 according to European plastics converter demand [5]. Over the past few decades, PVC recycled has been partially replaced in concrete as a fine or coarse aggregate. This article studies some properties of concrete including PVC recycled waste from Pipes. The results have compared with reference concrete mix have not PVC aggregate.

2 PVC CONCRETE

Polyvinyl chloride (PVC) is considered the important material in engineering construction. Many types are supplied such as all types of fluids and gas distribution pipes, doors, windows, profiles, pools, floor, and wall coverings, etc. Ground PVC scrap can be used as a partial replacement for concrete aggregate instead of being sent to landfill or incinerated. Fine or coarse natural aggregates in concrete can be partially replaced by PVC. Weight of concrete reduces by using recycled plastic in concrete, and thus decreases transportation costs [6]. plastic concrete can be used as lightweight concretes for structures requires lower strength because of the bulk density, and some mechanical properties of concrete containing waste PVC in any form are less than conventional concretes, [7, 8, 9]. Source of the waste, cleaning of the plastic from the inorganic components, and their respective ratios in the mix can occur a significant difference in concrete properties [10]. In the other hand, the plastics

in concrete can be used as insulation for hot, cold, sound, and saving energy [11]. PVC concrete also can be used to resistance chloride ions penetration in the structure [12].

3 MATERIALS AND METHADODOLOGY

In this study, normal concrete mixes and others containing PVC replaced with fine and coarse aggregate are conducted.

3.1 Materials

Ordinary Portland cement according to Libyan standard specifications [13] was supplied from Etihad factory. Coarse aggregate from Alouss town was used in the mixes and fine aggregate was from Zliten area, as well as normal drink water from tap was used. Granule recycled PVC of pipes divided to different size according of the sieves are prepared. Figure 1 shows some PVC used in the mixtures. To date, there is no specific standard categorise the size or replacement ratio of the PVC aggregate added in the concrete. Sieve analysis of the normal fine and coarse aggregate was carried out using standard sieves according to the European specifications EN933 [14] and the results of this analysis were in between of the standard limitation. Sieve analysis of recycled PVC also carried out by the same set of sieves. The remaining PVC on each sieve of the set was put an individually to use each as a separate substitution as a proportion of the natural aggregate in the mixes.



Figure 1. PVC sample used in the mixture

3.2 Methodology of the Study

Normal concrete mix has designed as a reference mixture (C0). Three other mixes have designed with replacing the aggregate by 10, 20 and 30% of PVC aggregate denoted by PC10, PC20 and PC30 respectively. A total of twenty-four mixtures, with six specimens for each mix have made in the same condition. Table 1 illustrates the materials weights for the four mixes. The mixes proportions and weights are shown in Table 2. The mix ingredients were mixed manually on a dry and then the water added. The water amount was changed for each mix to achieve the medium workability by slump test. The PVC was replaced by same weight of natural aggregate on each sieve. That is, the proportion of PVC aggregate was replaced with the corresponding weight of natural aggregate remaining on each sieve.

Cube moulds of 100 mm have been prepared after cleaning, then the inner surfaces of the cubes are coated/oiled by oil. Slump tests were conducted on each mix after the mixing has done. The water amount was controlled to be the slump results in medium workability (in between 50-70 mm). It is noticeable that as in table 1, the amount of water increases with the increase of the PVC content. The moulds were filled by concrete on three layers equally and each layer is compacted by vibrator. Then the moulds were left at room temperature ($\pm 25^{\circ}\text{C}$) for (24) hours. After one day, the samples were demoulded and submerged in water at room temperature for 7 and 28 days. After 7 days, half of samples from each mix (3 samples) were tested for compressive strength after drying the surface. At 28 days, Ultrasonic pulse velocity test were conducted first for the other specimens, and then compressive strength conducted directly after that on the same samples.

Table 1. The weights of mixes materials

Mix name	Cement content Kg	replacement of PVC %	Water weight Kg	Water cement ratio (w/c)	Fine aggregate Kg	Coarse aggregate Kg
C0	400	0	198	0.5	400	800
CP10		10	223.5	0.56		
CP20		20	240	0.6		
CP30		30	260	0.65		

Table 2. The weights of normal and PVC aggregate required for every mix

Sieve size mm	Required weight of aggregate per 1000g	Total required weight of aggregate per mix (g)	Required weight for every sieve per mix (g)			
			C0	CP10	CP20	CP30
8	25	10800	270	27	54	81
4	50	10800	540	54	108	162
2	200	10800	2160	216	432	648
1	250	10800	2700	270	540	810
0.5	150	10800	1620	162	324	486
0.25	200	10800	2160	216	540	648
0.125	125	10800	1350	135	270	405
Total	1000		10800	1080	2160	3240

4 RESULTS AND DISCUSSION

4.1 Workability

Slump tests were performed after mixing the materials. Table 3 shows the slump test results of the mixes. The slump results were in small rang (from 50 to 70 mm) as we arranged. However, the control of the mixing and method of the compacting the concrete in the cone plays a major role in the workability. The angular shape of the PVC aggregate may lead to an increase in friction between the particles and thus reduce the workability as the percentage of PVC increases.

Table 3. Slump tests of the mixes

Mix	Slump (mm)
C0	52
CP10	70
CP20	68
CP30	50

4.2 Compressive strength test

Compressive strengths were conducted on the samples at 7th day. The average of 3 samples results from every mix were calculated. Figure 2 illustrates the average of compressive strength resulted from the test. The other 3 samples of each mix were tested for ultrasonic pulse velocity at 28th day and directly have tested for compressive strength. The average results of the three samples were taken as illustrates in Figure 3. From Figure 2, the results at 7 days clearly show that strength increased in early age 12.1% with 10% PVC compared with the reference mix (0% PVC). The strength is significantly reduced by 3.4% and 37.7% with PVC 20% and 30%, respectively. Figure 3 (at 28 days) shows that the compressive strength of samples included 10% PVC increased by 0.33% compared with reference mix. At the same age, the strength decreased by 8.1% and 32.7% for the mixes included 20% and 30% of PVC aggregate respectively. From a practical point of view, the compressive strength of 28 days

expresses the considered strength, and the conclusion is that PVC aggregate can be added to concrete less than 10 percent to obtain normal strength.

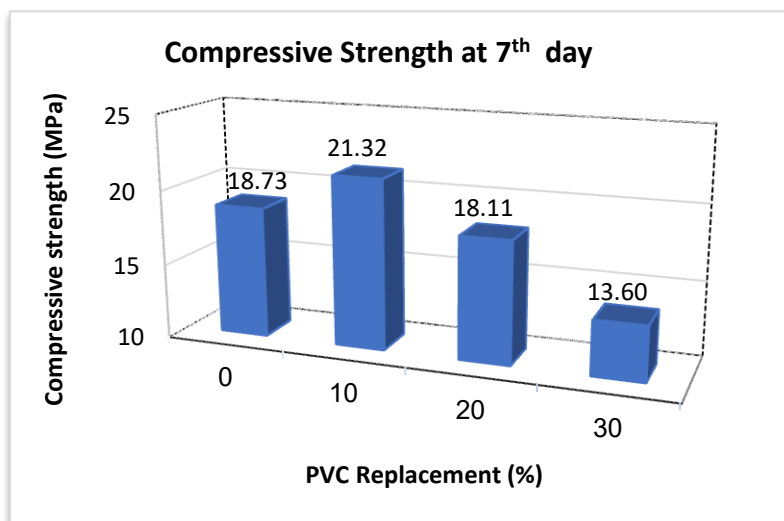


Figure 2 Compressive strength at 7th day of the mixes.

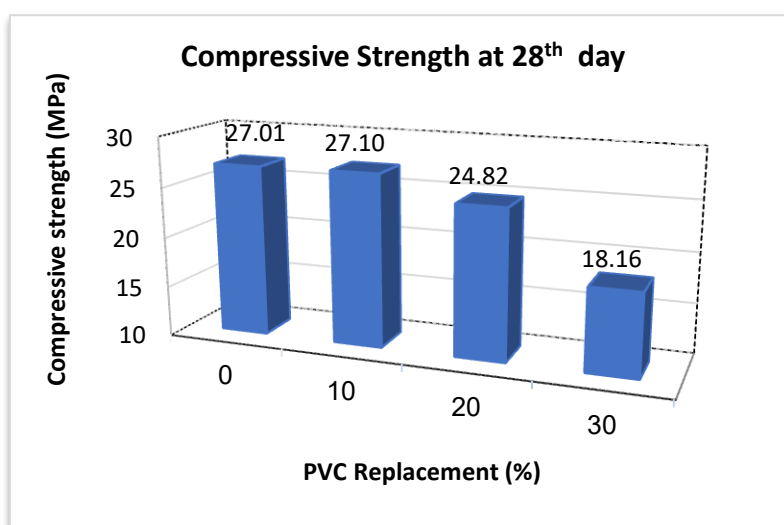


Figure 3 Compressive strength at 28th day of the mixes.

4.3 Ultrasonic pulse velocity

The ultrasonic pulse velocity (UPV) is a test to assess the strength and quality of concrete by measuring the velocity of an ultrasonic pulse passing through it. Samples were extracted from the immersion after 28 days, after which the UPV test has performed before the compression

test was conducted. An average of the three samples of UPV test was taken and the results are presented in curve as in Figure 4. The pulse velocity of concrete has slightly decreased by 2.6% for mixes with 10% of PVC aggregate, while significantly decreased by 16.8 and 23.8% for mixes with 20 and 30% of PVC respectively. These results show that the amount less than 10% of PVC can be acceptable in concrete.

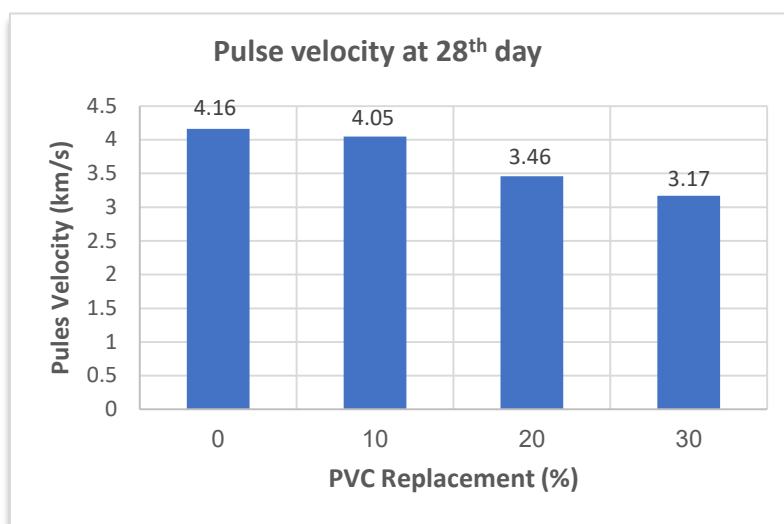


Figure 4. Pulse Velocity at 28th day of the mixes

4.4 Relationship between Compressive Strength and Ultrasonic Pulse Velocity Results

Ultrasound Pulse Rate (UPV) expresses the strength of concrete, which means that less porosity gives higher strength and vice versa. To connect the results between the two tests, the relationship has illustrated in Figure 5. obtained between the average of UPV and compressive strength, as well as the corresponding polynomial curve used to appropriate the results with a correlation coefficient of 1. From this curve it can be indicated that there is a significant increase in compressive strength versus a small increase in UPV with less than 10% PVC substitution. The results seem to show that for mixes with more than 10% PVC, UPV loses the increased compressive strength of concrete for velocities greater than 3.5 km/s. The observed deviations are likely due to differences in the properties of the elastic medium.

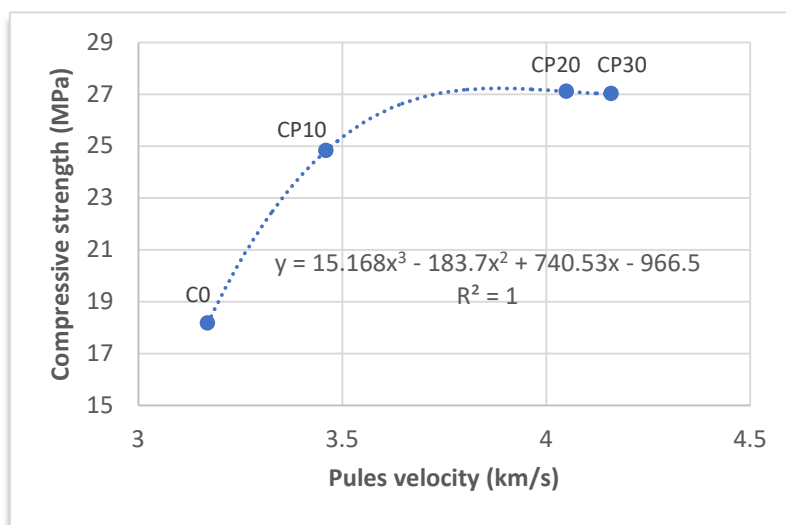


Figure 5. Compressive strength vs Pulse Velocity at 28th day of the mixes

5 CONCLUSION AND RECOMMENDATION

5.1 Conclusion

This study has aimed to find the properties of fresh concrete (workability) and hardened concrete (compressive strength and the size of voids in concrete by ultrasonic device). From the above discussion, it can be concluded that concrete containing PVC may provide better workability of concrete by increasing the amount of water with each increment of PVC aggregate replacement.

Through the laboratory study that was conducted and the analysis of the results of the tests, the following points were summarized:

1. When conducting slump test for concrete, it was noted that the results were in a small range despite the increase in the water amount with the increase in the PVC replacement in the mixture, which means that the workability decreases with the increase of PVC.
2. The compressive strength of concrete at 7 days gradually has increased with percentage of PVC in the sample 10% (CP10) compared to the reference sample (CP0), then it decreased in the rest of the samples (CP30 and CP20).
3. For the compressive strength at the age of 28 days, it has observed that this strength slightly decreased with replacement of 10% PVC in samples CP10, and then it significantly decreased in samples CP20 and CP30.

4. When conducting an ultrasound test for samples at the age of 28 days, it has noticed that the pulse velocity decreased a little for PC10 mix and then significantly for PC20 and PC30 the concrete mixture.

5.2 Recommendation

In this research, some properties of PVC concrete were studied, and an additional field of research was opened for future study. The following points can be studied to complete the vision about the use of PVC in concrete:

1. Some properties of PVC concrete as tensile, flexural strength could be conducted in the same condition of this study to compare them with compressive strength.
2. The use of fine aggregate of PVC in concrete is expected to lead to different results if coarse and fine aggregates were used.
3. Finding a binder to bond PVC and cement paste may lead to better results of strength and durability.
4. Comparing PVC concrete with the concrete of other types of plastics could be suggested to know the relationship between the types of plastics in concrete.

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تأثير استخدام البي في سي (PVC) المعاد تدويره كبديل جزئي للركام الناعم والخشن على بعض خواص الخرسانة

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الملخص

البلاستيك هو أكثر مادة مستخدمة في العالم. المشكلة الرئيسية هي بعد استخدام هذه المادة، حيث يتسبب تراكمها في حدوث مشاكل بيئية بسبب عدم قابليتها للتحلل. في الآونة الأخيرة، اهتم الباحثون بإعادة استخدام النفايات البلاستيكية في البناء. في هذا البحث دراسة تجريبية على استخدام بي في سي (PVC) المعاد تدويره كبديل جزئي للركام الناعم والخشن في الخرسانة. تم طحن أنابيب PVC المستخدمة بأحجام مختلفة وإضافتها إلى الخلطات الخرسانية. تم اعتماد نسبة استبدال 10، 20 و 30% بالإضافة إلى الخلطة المرجعية. تمت مناقشة نتائج الخواص الخرسانية مثل قابلية التشغيل ومقاومة الانضغاط وسرعة النبض بالموجات فوق الصوتية لخرسانة PVC. بشكل عام، فإن إضافة أقل من 10% من البولي فينيل كلوريد المعاد تدويره إلى الخرسانة يعطي نتائج مقبولة من خصائص الخرسانة. تؤدي زيادة نسبة استبدال PVC في الخرسانة بأكثر من 10% إلى نتائج عكسية حيث تقل الكثافة ومقاومة الانضغاط والمتانة. قد تُعزى القوة الميكانيكية المنخفضة للخرسانة إلى ضعف منطقة الانتقال البيني (ITZ) بين العجينة الأسمنتية وركام PVC.

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الكلمات الدالة:

خرسانة بي في سي.
بي في سي معاد تدويره.
نسبة إحلال البي في سي.
خواص خرسانة البي في سي.