Mechanical, thermal and acoustical properties of concrete with fine Polyvinyl chloride (PVC)

Hamid H. Hussein [1] **Osama A. Eedan** [2] **Mahmoud K. Ahmed** [3]

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Abstract

This study addressed some important tests for concrete including thermal, acoustic insulation and some mechanical behaviour of concrete containing granular Polyvinyl Chloride (PVC) waste as a sand replacement. The PVC waste was collected from a plant of manufacturing PVC doors and windows, was used to replace some of fine aggregate at ratios of 2.5%, 5%, 7.5%, 10%, 12.5% and 15% by weight Properties that studied are thermal conductivity, acoustic insulation slump, fresh density, dry density, compressive strength, flexural strength, and splitting tensile strength. Curing ages of 7, 28, and 56 days for the concrete mixtures were applied in this work. From the results of this study, it is suggested that using of 12.5% fine PVC as a sand replacement by weight can improve thermal insulation to about 82.48% more than concrete without plastic waste Acoustic insulation is about 43.09% more than reference mix and it satisfies the requirement of ACI 213R 2014 for structural lightweight concrete.

Key Words: Acoustic insulation, Thermal insulation, Structure light weight concrete

الخصائص الميكانيكية والحرارية والصوتية للخرسانة باستخدام البولي فينيل كلوريد

محمود احمد اسامة عيدان حامد حسين

الخلاصة

تناولت هذه الدراسة بعض الفحوصات المهمة للخرسانة، السلوك الحراري والعزل الصوتي وبعض الفحوصات الميكانيكية للخرسانة التي تحتوي على حبيبات النفايات البولي فينيل كلوريد (PVC) كبديل للرمل الطبيعي، تم جمع النفايات البلاستيكية من معامل تصنيع الأبواب والشبابيك البلاستيكية، وكانت تستخدم لتحل محل الركام الناعم في نسب 2.5٪، 5٪، 7.5٪، 10٪، 12.5٪ و15٪ كنسبة وزنية. الخواص التي درست هي التوصيل الحراري والعزل الصوتي والهطول والكثافة الطرية والكثافة الجافة، مقاومة الانضغاط ومقاومة الانحناء ومقاومة الشد الغير مباشرة، اعمار المعالجة كانت 7 و28 و56 يوم للخلطات الخرسانية في هذا البحث. من خلال نتائج هذه الدراسة، نقترح استخدام 12.5% من فضلات (PVC) الناعم كنسبة مئوية وزنية لاستبدال الرمل يمكن تحسين العزل الحراري (82.48%) أكثر من الخرسانة التي لا تحتوي على النفايات البلاستيكية وكذلك يحسن العزل الصوتي (43.09%) أكثر من الخرسانة المرجعية وتلبي متطلبات ACI 213R 2014 للخرسانة الانشائية خفيفة الوزن حاملة.

1. Introduction

Global warming is a phenomenon with large far reaching consequences. Reducing precious fuel consumption and recycling are only a couple of different ways that may reduce the adverse impact connected with global warming. Recent study (Al-Hadithi and Alani 2015, Bolat and Erkus 2016) confirms working with materials with high protecting properties can greatly reduce energy consumption and therefore, reduce global warming. Houses designed to make a balance between both the inhabitants and the environment This might not just provide higher quality of living for the occupants but gets the potential to reduce energy use and help stem the damaging effects of global warming. Concrete comprises three major part: aggregate, binder and water. The aggregate in concrete is about seventy-five percent of its total volume and for this reason, it takes an essential

[1] *Assistant Professor at the Department of Building and Construction Engineering, Technical Engineering College/Mosul.*
[2] *Lecture at the Department Building and Construction Engineering, University of Technology / Baghdad.*
[3] *MSc student at the Department of Building and Construction Engineering, Technical Engineering College/Mosul.*

role in the overall performance of concrete, (De Brito and Saikia 2012). The environmental caused by the increase in the extraction of natural resources and higher CO_2 emissions has given rise to seek out for more efficient, environmentally-friendly buildings. Has been employed to raise the strength and economical service life of slim buildings, to decrease the specific energy consumption and reduce the environmental impact of these activities (Al-Hadithi and Alani 2015). The improvement of physical performances of concrete in their lifespan can indirectly reduce the CO_2 emission by increasing their service life and reducing the basic requirements of materials for maintenance, (De Brito and Saikia 2012). The purpose of this study is to provide an attractive low-cost material with consistent properties, and increase the sustainability in concrete industry by using fine PVC waste as a combination to satisfied the requirements of the structural lightweight concrete with thermal properties, which have benefits such as reducing the use of natural resources, the wastes ingestion, avoiding environmentally polluting and economizing energy.

2. Materials

2.1 Cement

The cement used throughout this work is Portland cement (Type I). It is produced by united cement company (Tasluja-Bazian in Al-Sulaymaniyah /Iraq). The physical and chemical properties of the cement are given in Tables 1 and 2, respectively. Test results show that the cement conforms to (Iraqi Specification No.5 1984).

Table 1 Physical Properties of cement used.

Physical Properties	**Test Results**	**Limit of Iraqi specification No. 5/1984**
Specific surface area (Blaine method), m^2/kg	376	≥ 250
Setting time (Vicate apparatus) Initial setting, hr : min Final setting, hr : min	 2:05 4:00	 ≥ 0:45 ≤ 10:00
Compressive strength, MPa 3-day 7-day	 20.0 25.0	 ≥ 15 ≥ 23
Soundness (Autoclave method), %	0.12	≤ 0.8

Table 2 Chemical composition and main compounds of the cement used *

Oxide Composition	**Abbreviation**	**Content, %**	**Limit of Iraqi specification No. 5/1984**
Lime	CaO	66.11	----
Silica Dioxide	SiO_2	21.93	----
Alumina Trioxide	Al_2O_3	4.98	----
Iron Oxide	Fe_2O_3	3.1	----
Magnesia oxide	MgO	2.0	≤ 5 %
Sulphate	SO_3	2.25	≤ 2.5 %
Loss on Ignition	L.O.I	2.39	≤ 4 %
Insoluble residue	I.R.	1.29	≤ 1.5 %
Lime Saturation Factor	(L.S.F)	0.93	0.66-1.02
	Main Compounds (Bogue's equation)		
Tricalcium Aluminate	C_3A		< 3.5 %

*: *Chemical analysis was conducted by National Center for Construction Laboratories and Research*

2.2. Fine aggregate

Natural fine aggregate was used (Al-Ukhaider sand). The physical properties of sand shown in Table (3). The results indicate that the used sand conforms to the (Iraqi Standard No. 45 1984) and the second zone.

Table 3 Grading and physical properties of natural sand used in this investigation.

Sieve No. (mm)	Passing (%)	Limits of Iraqi specification No. 45/1980
10	100	100
No.4 (4.75)	95	90 - 100
No.8 (2.36)	79	75 - 100
No.16 (1.18)	59	55 - 90
No.30 (0.6)	39	35 - 59
No.50 (0.3)	15	8 - 30
No.100 (0.15)	6	0 - 10
The percentage of sulphate = 0.103 ≤ 0.5		
% passing sieve No 200 = 3.9 ≤ 5		
Specific gravity = 2.69		

2.3. Coarse aggregate

Natural crushed coarse aggregate with nominal size (5-20) mm was use in this study and it was from Nibai region. The sieve analysis test was done according to the (Iraqi Standard No. 45 1984). The properties of coarse aggregate used is shown in Table (4).

Table (4) Grading and physical properties of coarse aggregate used *

Sieve No. (mm)	Cumulative passing %	Limits of Iraqi specification No. 45/1980
20	99	95-100
10	42	30-60
5	2	0-10
Sieve No 200	0	≤ 3%
Specific gravity = 2.69		
Sulfate content = 0.09% (Iraqi specification requirement ≤ 0.1%)		
Absorption = 0.53%		

: physical analysis was conducted by National Center for Construction Laboratories and Research

2.4. Fine PVC (Polyvinyl Chloride)

The fine PVC was used in this study sand replacement in concrete. Fine PVC was collected directly from PVC doors and windows manufacturing plant from all governorates inside of Iraq. The fine PVC gradation conforms the (Iraqi Standard No. 45 1984). The sieve analysis results is shown in Table (5). A photograph of fine PVC shown in figure 1.

Table (5) Results of sieve analysis for fine PVC aggregate

Sieve size (mm)	Cumulative passing (%)	Limits of the Iraq standard No.45/1984
(4.75)	93	90-100
(2.36)	71	60-95
(1.18)	45	30-70
(0.6)	20	15-34
(0.3)	10	5-20
(0.15)	0	0-10
Fineness modulus = 2.72		
Specific gravity = 0.65		
Absorption = 0		

Figure 1. Fine PVC used

2.5. Water

Potable water, from the water-supply network system, was used for mixing and curing of concrete.

2.6. Chemical admixture

High range and water reducing admixture, with a trade name of KUT PLAST PCE 600 was used.

The purpose is to improve workability and to increase ultimate strengths with very high levels of water reduction in the concrete mix.

3. Experimental Program

3.1. Selection of Mix Proportions for Reference Concrete.

Reference concrete mix was designed according to (BS 1881 part116 1989) in order to obtained concrete with minimum compressive strength of 30 MPa at 28 days. The mix proportions were 1:1.63:2.4 (cement: sand: gravel) by weight with cement content of 433 kg/m³ and w/c ratio of 0.4. Several trial mixes were carried out to select the optimum dosage of high range water reducing admixture (HRWRA).

concrete containing different dosages of superplasticizer (HRWRA) are given in Table (6). According to manufacture instructions, the normal dosage of HRWRA is between 0.3 and 1.5 liters per 100 kg of cement (cementitious material). The results indicate that the best dosage of HRWRA is 1 liter per 100 kg of cement. This gives which brings about a 35.5% normal water reduction and maximum compressive strength of 47.6 MPa at 28 days.

3.2. Mixing procedure and initial results

The mixing process was performed in an electrical rotary mix of 0.1m³ capacity. The surface saturated dry (SSD) aggregate, sand, were mixed with the cement in a pan mixer for one minute. Then, the water was added to those ingredients and mixed with them for two minutes to reach the concrete mix homogeneity. The same procedure of mixing was carried out for the fine and coarse PVC in concrete mixes. The mixing was then continued for additional (2-3) minutes to obtain a uniform distribution of fine PVC (To prevent the conglomerate fine plastic) of PVC throughout the concrete mix. The procedure and time of mixing must be changed when using other types of mixers to achieve the required performance and homogeneity as recommended by (ASTM C305 1999). The details of mixes used are shown in Table (7).

Table (**6**) Trial mixes with variance dosage of superplasticizer

Mix proportion by weight	Dosage of S.P. (liters/100kg of cement)	w/c ratio	Slump (mm)	Water reduction(%)	Compressive strength (Mpa)	
					14 days	28 days
1:1.63:2.4	0	0.62	121	_	20.8	26.1
1:1.63:2.4	0.3	0.58	118	6.5	22.7	31.4
1:1.63:2.4	0.5	0.52	123	16	23.1	34.5
1:1.63:2.4	0.75	0.47	125	24	26.2	37.3
1:1.63:2.4	1	0.4	122	35.5	36	47.6
1:1.63:2.4	1.25	0.36	125	42	32.4	43.7
1:1.63:2.4	1.5	0.31	117	50	30.6	38.2

Table (7) The details of mixes used

Concrete Mixes	Mixes symbols	% Fine aggregate replacement by waste PVC	Mix proportion by weight
Reference	R	0	1:1.63:2.4 (Cement: sand: gravel) by weight with cement content 433kg/m³ w/c ratio = 0.4, HRWRA=1% of cementitious materials
Concrete contained fine PVC sand replacement	F-2.5	2.5	
	F-5	5	
	F-7.5	7.5	
	F-10	10	
	F-12.5	12.5	
	F-15	15	

4. Experimental Tests

4.1. Fresh Concrete Tests

4.1.1. Workability (Slump Test)

The workability of all concrete mixes was measured immediately after mixing in accordance with test method of (ASTM C143M 2007)

4.2. Testing Hardened Concrete

4.2.1. Dry density

The measurement of concrete dry density was carried out according to (ASTM C642 2013), using cylindrical sample (100 x 200) mm. The results recorded as an average result of three samples at 28 days age for each mix. The concrete specimens were dried out in oven at 100-110 C^0 for 24 hours then weighted, after that the specimens were submerged in water for forty-eight hours, Finally the sunken weight of specimens were obtained.

4.2.2. Compressive strength

The measurement of concrete compressive strength was carried out with a digital compression machine of 2000 KN capacity according to (BS 1881 part116 1989). Samples size was 100 mm cube, and the average three samples were recorded at 7, 28 and 56 days age for each mixture.

4.2.3. Splitting tensile strength

The measurement of concrete splitting tensile strength was performed using a digital compression machine of 2000 KN capacity according to (ASTM C496 2007). This was done by using cylinder with size 100*200 mm and the load was used consistently up to failing. The average result of three cylinders was determined at 7, 28 and 56 days age for each mix.

4.2.4. Modulus of rupture

The measurement of concrete flexural strength was carried out, by a digital TESTING machine of 2000 KN capacity, according to (ASTM C78 2005) and following the method of Third-point-loading. This was done by using (400 x 100 x 100) mm samples and the load was applied continuously up to failure. The average result of three prisms was calculated at 7, 28 and 56 days' age for each mix.

4.2.5. Thermal conductivity

Thermal conductivity property (K) may vary locally with temperature, humidity, material composition, direction. Knowledge of local thermal conductivity is important in the evaluation of heat transfer rates.
Therefore, a special mold was prepared to produce the required specimen with diameter of 75 mm and 30 mm thickness, two specimens were used for each mix and tested at (28 days).
Hot disk method was used for determining the thermal conductivity coefficient (K). The Hot Disk TPS 500 Thermal Constants Analyzer, quickly and accurately measures the thermal conductivity of a wide range of materials.
Advantages of TPS technology as realized in the Transient Plane Source (TPS)TPS 500 are:

- Surface roughness or surface color does not influence measurement results.
- Contact pressure of sensor to sample surface does not influence the measurement results.
- The method is non-destructive.

The main concepts of this test

On the premise of the hypothesis of the TPS method, the Hot Plate Warm Consistent Analyzer uses a sensor component fit as a fiddle of a twofold winding. this hot plate sensor acts both as a warmth source to expand the temperature of the specimen and a resistance thermometer to record the time-subordinate temperature increment. In most cases, the sensor component is made of a 10-µm-thick nickel metal twofold winding with exact measurements (width and number of windings and their radii).

The main output data

This permits estimations over the temperature range from 10 to 500 K, and the standard vulnerability of the deliberate warm conductivity is ±0.002 W/m*k. The TPS's rule, methodology, and technique have been examined by (Log and Gustafsson 1995) and (Nagai, et al. 2000).

4.2.6. Sound insulation

Acoustic insulation was measured using the locally made acoustic insulation measurement available in University of Technology/ Materials Engineering Department. It consists of four parts: wave generator device (UNIT 092812), device to amplify the wave (TNG, type: AV 298), laud speaker and wave receiving device (RANGE 30 dB - 130 dB). The test started when the wave was generated by the wave generator device and then amplified. The wave then transferred to a loud speaker attached with a wooden box. The specimen was placed in the middle of this box, then the box was closed and then the wave at different frequencies (about 19 frequencies) was applied. For every frequency, the wave was taken from the receiving wave device. This test must be done in a very static medium and without any movement in the whole place, because this may lead to an imbalance in the obtained results. The sample used in this test has dimensions of (240 × 240 ×50 mm). This test was done to pure concrete sample, concrete contained fine plastic as a sand replacement with different percentage of replacement (2.5,5,7.5,10,12.5 and 15%). It was possible to determine the equivalent absorption area and absorption coefficient of the samples using equations (1) and (2), respectively (Famighetti and Tina 2005)

$$A = (0.921 * V * d)/c \qquad (1)$$

Where, *A* is equivalent absorption of absorbing material (metric Sabines), V is room volume (m^3), c is speed of sound (m/s), and d, decay rate (dB/s).

Normalizing *A* by dividing by the specimen area was measured in (m2) unit, S, yields the dimensionless absorption coefficient, α (Famighetti and Tina 2005).

$$\alpha = A/S \qquad (2)$$

Where, α is sound absorption coefficient, and S is Surface area of sample.

$$NRC = (\alpha 300 + \alpha 600 + \alpha 2000 + \alpha 6000)/4 = A/S \text{(Thumann and Miller 1996)} \qquad (3)$$

Where NRC is noise reduction coefficient.

5. Result and discussion

5.1. Fresh properties of green concrete

5.1.1. Workability tests (Slump test)

Table (8) shows the results of the workability tests (slump test) for the different mix proportions of concrete contain different percentage of PVC. The result of slump test when use fine PVC as a fine aggregate replacement experienced a loss of slump. It is possible to have a homogeneous mix for all the studied mix proportions using w/c ratio of 0.4 with the aid of using water reducing admixtures (Superplasticizers). All mixes within the slump range (120 ± 60mm). Also, it was noticed that the effect of Superplasticizers on the fresh concrete because in this study use weight percentage of sand replacement on the other hand the surface area of PVC is higher than the surface area of sand for the same weight percentage (Ismail and Al-Hashmi 2008) and (Kou, Lee, et al. 2009) report similar results with concrete containing aggregates with similar types. But (Choi, et al. 2009) obtained higher slumps than for conventional concrete when increasing amounts of smooth and regular shaped plastic aggregates were added to the concrete mix

5.1.2. Fresh Density

Their results indicated that the fresh density of concrete containing 2.5%, 5%, 7.5%, 10%, 12.5% and 15% plastic aggregate as a replacement of fine aggregate tends to decrease by 3.8%, 6.26%, 10.64%, 12.23%, 14.61% and 18.41% respectively, below the reference concrete.

Table (8) Effect of fine PVC on fresh density and workability of concrete

Samples	Materials								
	Cement (kg/m^3)	**Coarse aggregate (kg/m^3)**	**Sand (kg/m^3)**	**Wt. of fine PVC (kg/m^3)**	**Fine PVC (%)**	**W/C**	**Slump (mm)**	**Fresh density (Kg/m^3)**	**Redaction in fresh density (%)**
R	433	1039.2	705.79	-	-	0.4	166	2443	-
F-PVC-2.5	433	1039.2	688.15	17.64	2.5	0.4	162	2350	3.8
F-PVC-5	433	1039.2	670.5	35.28	5	0.4	154	2290	6.26
F-PVC-7.5	433	1039.2	652.86	52.93	7.5	0.4	139	2183	10.64
F-PVC-10	433	1039.2	635.21	70.57	10	0.4	122	2144	12.23
F-PVC-12.5	433	1039.2	617.57	88.22	12.5	0.4	109	2086	14.61
F-PVC-15	433	1039.2	105.86	105.86	15	0.4	83	1993	18.41

5.2. Hardened State

5.2.1. Dry densities

The dry densities of concrete contained plastic waste are less than the dry densities of reference mix as shown in Table (9). The lower density of concrete contains plastic aggregate is due to lower density of PVC aggregate than natural aggregate (Kou, Lee, et al. 2009). The dry density results show that concrete mix containing 15% weight replacement of fine PVC can be reduced the density of reference concrete (2331kg/m^3) to (1892kg/m^3). According to (ACI 213R 2014) the oven dry densities of structural lightweight concrete are between 1775-1910 kg/m3, therefore this concrete mix is classified as structural lightweight concrete. However, the density of concrete mixes conforms to the requirements of structural LWAC. According to RILEM classification the maximum density for lightweight concrete is to 2000 kg/m^3 (RILEM 1975). Concrete mixes containing fine PVC as a replacement to natural fine aggregate also show a reduction in dry density relative to the corresponding mix without plastic material waste aggregate. These decrements the reason might also as a result of the diffidence in the mix proportions due to PVC replacement by weight not by a volume. as a result of low specific gravity of fine PVC aggregate when compared to natural fine aggregate.

5.2.2. Compressive strength

Table 9 are illustrating the compressive strength for various concrete. The results that the compressive strength of (F-12.5) with satisfied the requirements of the structural lightweight concrete on the other hand compressive strength more than 17 MPa at 28 days age (ACI 213R 2014). While, for the F-15 can be used only for insulation purposes. From the result shown in table (9), the compressive strength decrease with increase the weight replacement of fine PVC. The redaction in compressive strength when fine PVC replacement are 15.54, 22.9, 38.44, 50, 57.14 and 68.9% for mixes F-2.5, F-5, F-7.5, F-10, F-12.5 and F-15 respectively. These results are in contrast with those of prior researches carried out on other types of clear plastic waste (Marzouk, Dheilly and Queneudec 2007) and (Bolat and Erkus 2016) The current result can be related to: (1) Initial generated cracks around the PVC particles which have lower modulus of elasticity than pure cement paste. (2) Low bonding strength between the PVC aggregate and cement paste. (3) Internal bleeding from the completely saturated lightweight aggregates. (4) The coarser size of the PVC granules led reduce in packing of the concrete.

It could be observed that superplasticizer contributes to a considerable improvement in both 14 and twenty-eight days compressive strength and causes a decrease in w/c ratio compared to the reference mix. The main reason for this is the mode of action of the superplasticizer, that when a surfactant with great number of an ionic polar group in hydrocarbon chain is included in cement-water system, the extremely chain is adsorbed on the surface of cement particles.These surfactants provide strong negative charge with high repulsing effect،which helps to lower the surface tension of the adjacent water and the genuine cement particles hydrophilic (water attracting) for greatly boosting the fluidity of the arrangement. Consequently, lower amount of water is required to attain equal workability (Neville 1995).

5.2.3. Splitting Tensile Strength

The splitting tensile strength of the concrete is shown in Table (9). The splitting tensile strength decrease with the increase in PVC content. This behavior comparable to that observed for compressive strength. It is probably because the similar reasons explained before. (Mindess, Young and Darwin 2003) claimed that the splitting tensile strength of concrete is inspired by the properties of the interfacial transition zone (ITZ). The water cumulative on the smooth surface of PVC particles may cause a weak bond between the fine PVC and cement paste. As present in Table (9) after achieving the ultimate strength, most of the PVC granules in the concrete matrix do not fail, but the failure beginning in the bond region between the PVC particles and cement paste.

5.2.4 Flexural strength (modulus of rupture)

Test result of flexural strength are illustrated in Table (9). These results show that the flexural strength of concrete contained plastic aggregate decrease with increase the plastic aggregate weight replacement. This pattern may be attributed to the decline in adhesive strength between the surface of plastic waste aggregate and the cement paste. This kind of waste may be as a result of fibro-form of fine PVC clear plastic waste aggregate, 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 concrete matrix has cracked.

Table (9) Results of concrete at Hardened State

Mix code		R	F-2.5	F-5	F-7.5	F-10	F-12.5	F-15
Dry density (Kg/m³)		2331	2213	2194	2059	2029	1967	1892
Compressive Strength (MPa)	7days	33.4	28.3	24.8	19.5	16.3	14.7	10.1
	28days	47.6	40.2	36.7	29.3	23.8	20.4	14.8
	56days	52.7	42.5	39	32.6	25.2	21.2	15.4
Splitting Tensile Strength (MPa)	7days	2.3	1.8	1.6	1.5	1.3	1.1	0.8
	28days	3.2	2.6	2.4	2.3	2	1.9	1
	56days	4.1	3.8	3.2	3	2.7	2.2	1
Flexural strength (MPa)	7days	2.6	2.1	1.9	1.6	1.4	1.1	0.8
	28days	3.4	2.6	2.3	1.9	1.7	1.5	0.9
	56days	3.9	3.2	2.8	2.2	1.8	1.6	1

5.3. Physical properties

5.3.1 Thermal conductivity of concrete.

The thermal conductivity results are illustrated in Table (10). From these result, the thermal conductivity of F15 is (90.21%) more than reference mix. However, this type can be used for insulation purpose only. F12.5 satisfies the requirement for structural lightweight concrete with thermal conductivity (82.48%) more than reference mix.

Table (10) results of thermal conductivity of concrete contained fine PVC

Mix code	R	F2.5	F5	F7.5	F10	F12.5	F15
Thermal conductivity (W/m.k)	1.37	1.108	1.033	0.661	0.5291	0.2307	0.1289
Increase in thermal conductivity (%)	-	15.87	21.56	49.81	59.82	82.48	90.21
Heat transferred per unit time (W/h)	3755.4	3159.4	2945.5	1884.8	1508.7	657.8	367.5
Heat resistivity (m^2/kw)	0.075	0.0902	0.0968	0.1512	0.1890	0.433	0.775

5.3.2. Acoustic Insulation Results

The ability of concrete to absorb sound can be measured using the sound absorption coefficient (α) according to (ASTM E336 2016). The sound absorption coefficient is measured under three different frequency: (1) low frequency (100,200-500 Hz), (2) Mid frequency (600,700-1000 Hz) and (3) high frequency (2000,3000-10000 Hz). The result showed that the concrete with plastic sand replacement have superior sound absorption properties to that of reference concrete. This is in particular for low, mid and high frequency. The ability of material to absorb sound can be indicated by using one value called noise reduction coefficient (NRC). The NRC result and the sound level result are shown in figure (3) and (4) respectively. From the result show in table (11) NRC is (57.45%) more than the reference concrete when use 15% fine aggregate replacement these result is more effect.

Table (11) results of thermal conductivity of concrete contained fine PVC

Mix code	R	F2.5	F5	F7.5	F10	F12.5	F15
NRC ($*10^{-6}$)	8.346	9.361	10.1	10.79	11.16	11.943	13.143
Increase in NRC (%)	-	12.15	20.99	29.28	33.7	43.09	57.45

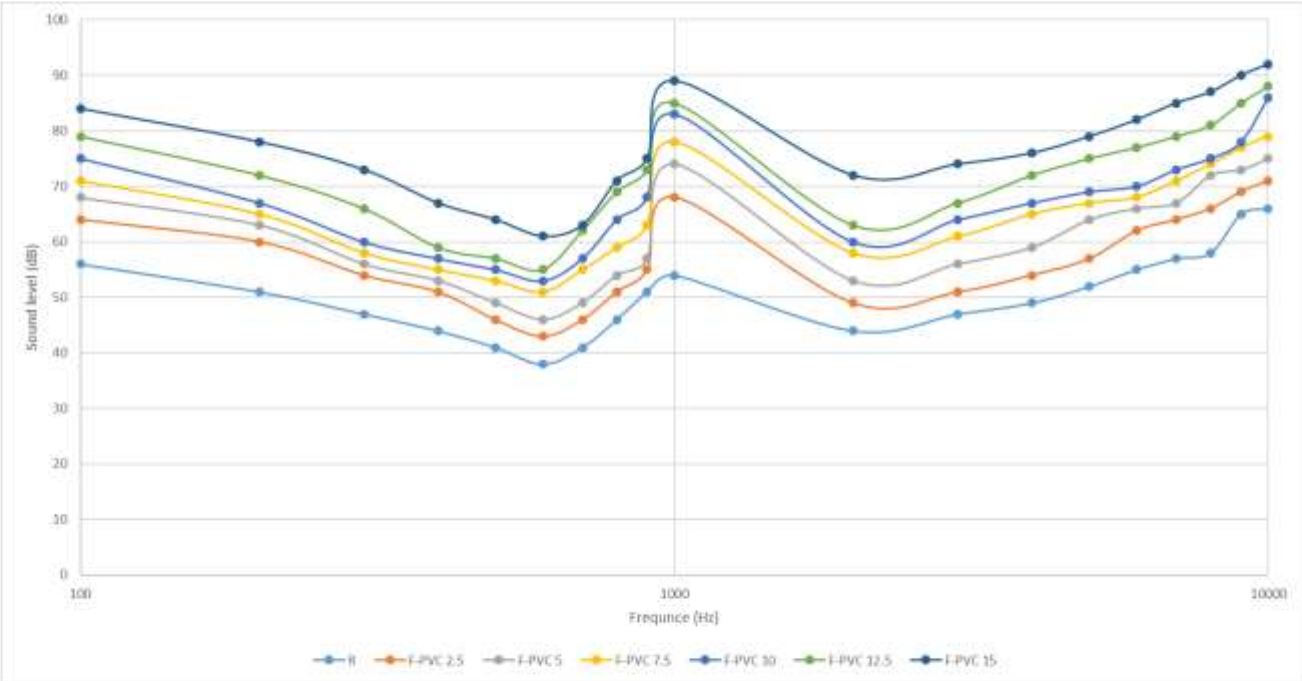

Figure 3. The effect of use fine PVC on sound level result.

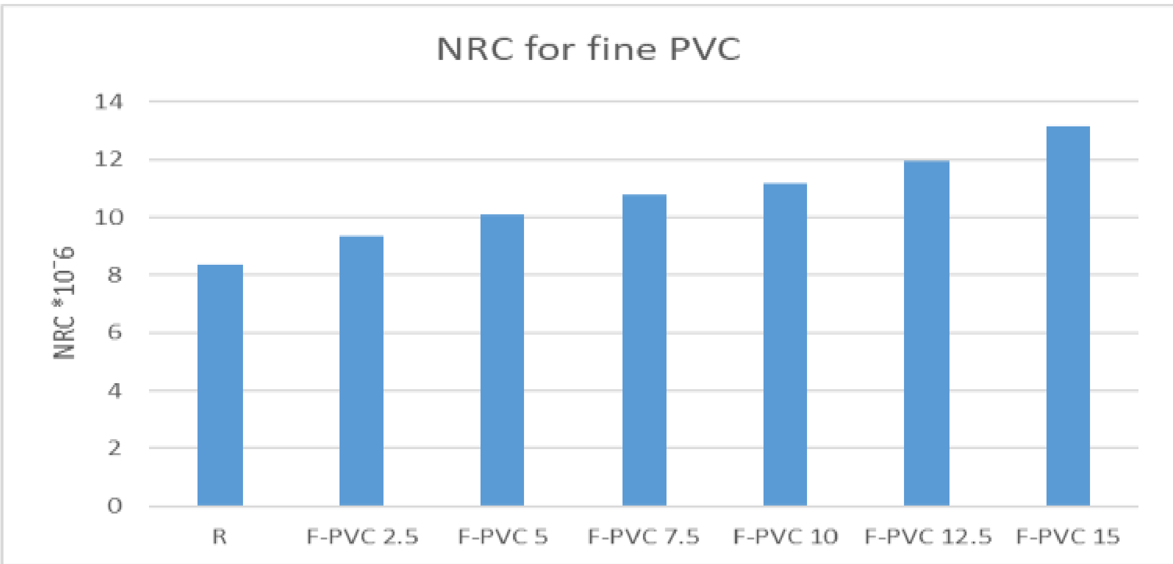

Figure 4. The NRC result when use fine PVC

6. Conclusion

- By replacing sand with fine PVC at 2.5,5,7.5….15% the density can be reduced from 5% up to 19% depend on the content of fine PVC.
- The sustainable concrete exhibits superior thermal and acoustic properties than plain concrete measured by the decrease in thermal conductivity coefficient (k) and the increase in sound absorption coefficient (α) and noise reduction coefficient (NRC).
- The PVC concrete satisfy the requirement for (ACI 213R 2014) for structural light weight concrete for F 12.5 with thermal conductivity 82.48% more than plane concrete.

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