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# Effect of adding depolymerized polyethylene terephthalate waste on the acoustic insulation and hardness properties of Iraqi cement mortar

***Amjed M. Hameed*** [1], Mohammed Alzuhairi[1], Sarmad Imad Ibrahim[1]***

[1] Department of Materials Engineering, University of Technology, Baghdad, Iraq

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***Corresponding Author:**
*Amjed M. Hameed*
amjed.majeed.hameed@gmail.com

**Abstract**

In this study, depolymerized Polyethylene terephthalate waste (DPET) particles were prepared by bubble column reactor adding ethylene glycol as a solvent and Nano MgO (65nm) as a catalyst and then using DPET particles to modify the cement mortar composite by partial replacement of sand. The mechanical hardness test, the physical ultrasonic pulse velocity (UPV) test and the acoustic insulation test of the modified cement mortar composite have been studied. DPET particles were used with four percentages of (1%wt, 3%wt, 6%wt and, 9%wt) of sand for each one of them. All tests were done for 28 days of curing. The cement mortar composite was prepared using water/cement ratio of (0.48) while sand-to-cement material ratio of (1:2.75) (2.75 parts of sand and 1 part of cement). The findings showed that there was no clear influence of DPET on the hardness of the cement mortar composite, where the hardness of mixture with 3% DPET equal to that of mixture with no DPET was (91.7 shore A), while the hardness of other mixtures with (1, 6 and 9)% PET were (91.6, 91.2 and 90.8 shore A) respectively. While the UPV of the modified cement mortar composite decrease with increase the amount of DPET particles, where the drops in UPV were (-2.98%) at 9% of DPET particles. The acoustic insulation of the modified cement mortar composite increase as the DPET increases in all frequencies that were used. This is indicate that DPET particles which that made through depolymerized the PET of waste water bottles can enhancement the physical and insulating properties of the cement mortar. The findings concluded that, the using of waste materials after apply treatment process on it such as de-polymerization is better than using it directly.

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## 1. Introduction

The existence of vast amounts of waste plastics, as well as their low biodegradability, has a negative impact on the environment. Also, all plastic types used in day-to-day activities is eventually become wastes and cannot be entirely recycled right away, necessitating the storage of tons of plastic waste [1]. Reusing wastes is significant from a variety of aspects; it decreases pollution and energy production, it helps in recycling, and helps in the preservation and conservation of non-renewable natural resources [2].

Concrete is the most widely used materials next to water [3]. Water, aggregate, and cement, which are its raw materials, are inexpensive and abundantly available. Those raw materials are the primary constituents of concrete; it is a commonly utilized in the industry of construction [4]. Aggregate makes up 65–80% of the concrete's volume and has a significant impact on its characteristics like permeability, strength, workability, durability and volume stability. For the production of huge amounts of concrete for worldwide consumption, enormous quantities of coarse and fine aggregates are needed [5].

The use of waste materials in preparing concrete can eliminate large quantities of waste materials. This approach can address environmental concerns related to aggregate mining and waste disposal and solve problems involving the lack of aggregates in construction sites [6, 7].

Plastic wastes can reuse in construction regarded an optimum option to dispose plastic wastes among the various forms of recycling management methods. Recycled plastics can be reused with no deterioration in quality throughout the cycle of the service, while recycled plastic might also be utilized instead of virgin construction materials. Recently, using recycled plastics in composite cementations was thoroughly extensively studied. Furthermore, plastics were primarily employed in concrete as Plastic Aggregates (PA) that substituted natural aggregation. Many studies have been investigated the qualities of the hardness and fresh concrete including plastic materials [8–12].

Sheelan M. Hama, et al., [13] studied using waste water bottles made from polyethylene terephthalate (PET) as fiber form, manufacturing by self-compact concrete. PET fiber was used with five different content of (0.5%, 0.75%, 1%, 1.25% and 1.5%) by cement weight. Results shown that the compressive strength firstly, was increased with PET content up to (0.75%), which improve about 4.6%, and when PET content upper than (0.75%), the compressive strength decrease to (-15.2%).

Awham Mohammed Hameed et al., [14] studied the use of recycled plastic aggregate (RPA) made from PET with the mortar. RPA in form of flake aggregates were used as five different partial replacement percentages (1%, 3%, 5%, 7% and, 10%) by the cement weight. The results shown that the dry density of the mortar is reduced by adding RPA to the mortar, which decrease to 14% for the 10% RPA. While the compression strength of the mortar increased slightly at (1%) RPA aggregates and then decreased with increase in RPA percentage to reach about (19.27%) for content (10%) RPA aggregates.

A. S. Benosman, et al., [15] studied the use of waste polyethylene terephthalate (WPET) on mortar.WPET aggregate were used as three different partial replacement percentages (6, 12 and, 17) % by weight of cement. The results shown that compression strength of the mortar with the WPET aggregate was comparatively less than of the mortar without WPET aggregate. This drop in the compression strength increased by increasing in WPET content, which reached to (63%) for (17%) replacement.

W. Gh. Abdul Hussein, et al., [16] studied the using of waste plastic recycled as fine aggregates, to manufacturing a lightweight cement mortar. Recycled plastic aggregates was used with five different content of (20%, 40% and, 60%) by sand weight. Results have shown that acoustic isolation was increased in all tested samples content of recycled plastic aggregates, and upper value was (99%) for (60%) of recycled plastic aggregates.

## 2. Experimental Work

*2.1* Materials

The materials that used in prepare cement mortar were: A) the Ordinary Portland cement type II made in Iraq, with a 1.441g/cm3 density and 149min first setting time and 270min final setting times. Table 1 shows the chemical compositions of cement. B) Sand that available in the local market in Iraq, with a 1.70g/cm3 density, 2.63 fineness modulus and particles size less than 4.7mm. C) Tap water.

**Table 1:** The Chemical Compositions of Cement

| $SiO_2$ | $Fe_2O_3$ | $SO_3$ | MgO | $Al_2O_3$ | CaO |
|---|---|---|---|---|---|
| 20.14 | 3.71 | 1.83 | 1.96 | 5.24 | 61.59 |

*2.2* Glycolysis of PET

Firstly, many drink water bottles made from PET has been collected after used. These bottles were washed and cleaned, after that cut off into small pieces manually (about 3-6mm). Second step is de-polymerization of PET: the PET depolymerized was done via applied Nano-MgO (60) nm as a catalyst and ethylene glycol (EG) as solvent in three phase bubble column reactor and at 197C° (boiling point of EG), see figure (1). The process takes less than one hour to get a homogenous liquid. The homogenous liquid was quickly losing the heat and freeze at room temperature thereby change from liquid to wax and then to solid white material. This solid white material, at this stage consists of depolymerized PET (DPET) and EG state by each other, so must be separate them.

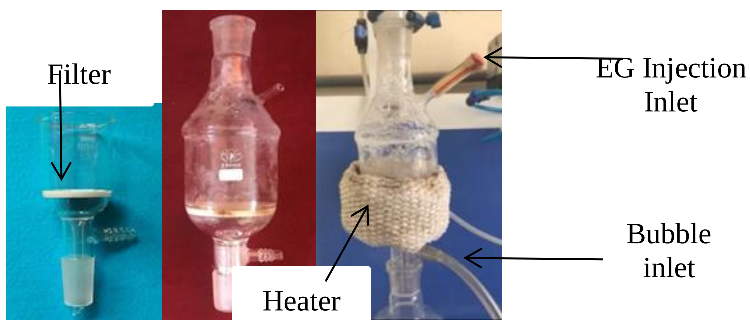


**Figure 1:** The Bubble Column Reactor.

Third step is the physical split-up process: the solid white material in the beaker content from DPET and EG melting together in figure (1). Via take advantage of the large difference in melting point between them, to rid DPET from EG, heating the beaker to reach up 197 C° (milting point of EG), the EG was evaporated and DPET stay in beaker as liquid form see figure (2).

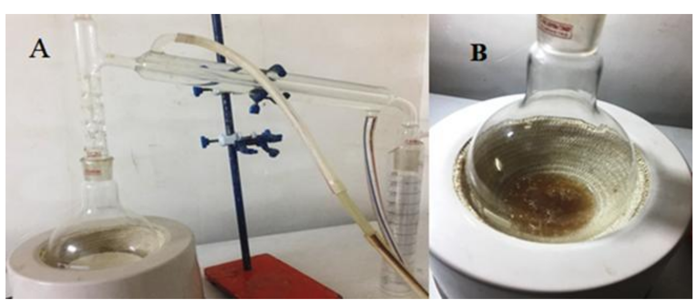


**Figure 2:** A. The Physical split-up process. B. DPET stays in beaker.

In the fourth step, the DPET was poured in beaker as show in figure (2, B) in flat plate to freezing at room temperature, see figure (3, A). Fifth step was milling process, after the DPET cool, remove it from flat plate and was easy crushed to flaks form, the flaks of DPET was mild by using milling machine, The sixth stage was purification and washing the DPET to remove any dust or leftover EG. Final step is milling DPET, after drying the pieces of DPET put those to milling machine for final milling process see figure (3, B).

**Figure 3:** A. DPET after remove EG, B. Milling process of DPET.

*2.3* Manufacturing of Mortar

The purpose of the experiments in this section are adding DPET powder affected the physical, mechanical, sonic, thermal, and structural features of cement mortar. There are two groups to prepare cement mortar mixtures; the first group is used a single mixture of sand, cement, and water with no DPET. The mortar of this group is a reference mortar for mortars of the second group. While the second group is contain DPET particles and included four mixtures, each one of them had different concentration of the DPET. The DPET powder is used as a partial replacement of (1, 3, 6 and 9 %) per weight of sand. In order to achieve these steps, numbers of samples cement mortar mixtures are designed and casting in molds according to the specification of each test and then put in curing bath. All the mixtures had a (w/c) ratio of (0.48) and sand-to-cement material ratio of (1:2.75) (2.75 parts of sand and 1 part of cement). By weight of the fine aggregates (sand), the percentages of DPET powder were (1, 3, 6, and 9%). Table (2) lists the proportions of the cement mortar combinations.

**Table 2:** Details of Mix Proportions

| The Groups | DEPT<br>% | Sand<br>% | Cement<br>% | C/W<br>Ratio | S/C<br>Ratio |
|---|---|---|---|---|---|
| MDPET0 | 0 | 100 | 100 | 0.48 | 1:2.75 |
| MDPET1 | 1 | 99 | 100 | 0.48 | 1:2.75 |
| MDPET3 | 3 | 96 | 100 | 0.48 | 1:2.75 |
| MDPET6 | 6 | 93 | 100 | 0.48 | 1:2.75 |
| MDPET9 | 9 | 91 | 100 | 0.48 | 1:2.75 |

The mixtures were prepared in accordance with ASTM C 305-12 [92]:

The first stage was weighing the constituents of the mixture by using a sensitive digital balance of 0.01gm. If the mortar mixture is not containing DPET powder, sand and cement have been manually mixed till reaching a homogeneous appearance. After that, the mixture is placed in the electrical mixer, the amount of water is added gradually to the mixture, and mixing for (4) minute. In case of the mortar mixture contained DPET powder, the procedure stays same as in the previous mixture except added DPET to cement and sand when mixing in the first step. The second stage is casting, which involved selecting a mold for each test and oiling the inside of the mold to make the casting easier. Also, the mold has been placed on soft board in order to ensure that specimen's base was defect-free. The samples were densified in 2 layers on vibrating table, with every one of the layers vibrated for ten seconds. With the assisting of a spatula, the samples' surfaces were finished. To avoid moisture loss, the molded samples were covered by a wet burlap for the first (24) hours. The samples were removed from the molds carefully after 24 hours. Then, the samples were entirely immersed in water storage tank containing water in a temperature of about (28-30)℃. Mortar samples were cured until the time of testing.

### *2.4* Test

Several non-destructive tests were performed on cement mortar so as to find the effect of DPET powder on the physical and sonic properties of cement mortar, these non-destructive tests were included: hardness test, ultrasonic pulse velocity test and, acoustic insulation test.

#### *2.4.1* Hardness Test

Based on Standards ASTM D2240[17], hardness test of cement mortar samples was done with the use of the available (Dorumeter) hardness tester, type (Shore D) hardness testing with a depressing time of measuring of 10sec, and that is through taking five reading on every one of the cube faces expect the top one that is exposed to the air.

#### *2.4.2* Ultrasonic Pulse Velocity (UPV) Test

Depending on the British standard BS1881/ part 203/1986[18], the ultra-sonic pulse velocity test (UPV) of the cement mortar samples was achieved with use of available portable ultra-sonic nondestructive indicating tester (PUNDIT, Lab PROCEQ Co.) Switzerland. There have been 2 transducers fitted to cables of the instrument, one acts as ultra-sonic pulse transmitter, and the other one plays the role of a receiver. The two transducers have been held against the sample’s surface with the use of the coupling agent grease or the petroleum jelly has been applied between tested surfaces of sample and the contact faces of transducers for the purpose of ensuring sufficient transmittance of the pulse. In this testing, a longitudinal vibration pulse with the 54kHz resonant frequencies was created by electro-acoustic transducer and after that, it was converted to electrical signal by the receiver transducer. This Testing was performed in NCCLR.

#### *2.4.3* Acoustic Insulation Test

The level of the acoustic insulation was evaluated using locally made measurement device of the acoustic insulation based on the ASTM E336[19] (Univ. of Technology/ Dept. of Materials Engineering), as can be seen from figure (4). It includes 4 parts, which are: wave amplification (TNG, type: AV298), the UNIT 092812 wave generator device, wave receiving device (30dB - 130dB) and loud speaker. This test had begun when wave was produced by the UNIT 092812 and amplified after that. Then, this wave was transferred to the loud speaker that was attached to wooden box.

The sample was placed in the middle of that box, then the box closed and then wave at a variety of the frequency values (approximately 15 frequencies) was applied. For each one of the frequencies, the wave has been obtained from the wave receiving device. This testing has to be carried out in highly static medium and with no movements in the entire place, due to the fact that it could result in the imbalance of results. The sample size was utilized in this testing was ($5 \times 5 \times 5 cm^3$) dimensions.

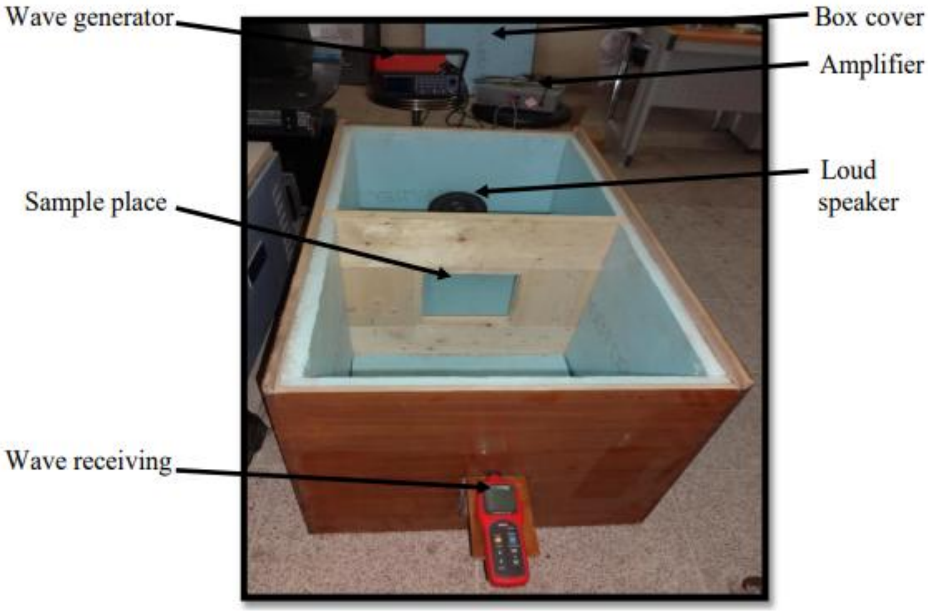


**Figure 4**: Acoustic Insulation Test Device

## 3. Results and Discussion

### *3.1* Findings of Hardness Test

The findings of hardness test of all five cement mortar mixtures for standard age (28 days) are displayed in figure (5). From figure (5) the next findings can be noticed, the hardness of most cement mortar composite mixtures containing DPET particles (MDPET1, MDPET6 and MDPET9) are very slightly affected by DPET particles at standard age (28 days). The mixtures (MDPET1, MDPET6 and MDPET9) have hardness lower than hardness of the reference cement mortar mixture with no DPET particles (MDPET0). The mixture (MDPET3) hardness is equal to the reference cement mortar mixture with no DPET particles (MDPET0). After 28 days of curing, the hardness drops to the minimum value (90.8 Shore A) at MDPET9 that contains DPET particles of (9%). The maximum detraction in the hardness by effect of DPET particles of (9%), at 28 days was (-0.98%). There is not clear influence behavior of DPET particles on the hardness of cement mortar composite. The DPET influence on cement mortar composite is small and can negligible.

Through the above points, notice that the hardness of the cement mortar composite is not much affected by the DPET particles when replace it instead of sand although DPET particles are less hard than sand, this is maybe because the nature of hardness property and its measurement is on the surface of the cement mortar and seems that the influence of DPET particles is affected inside the mortar. There are two causes; the first one is the small DPET particles size (4.8μm) enables it to be located between other large particles and far from the surface, thus the sensitivity of the hardness measuring cannot be sensed or affected by its presence. While the second cause is simply the amount that used is small to effect on the hardness of the cement mortar composite, even the upper dose (9%) that used in this study its effect was not significant to be (-0.98%).

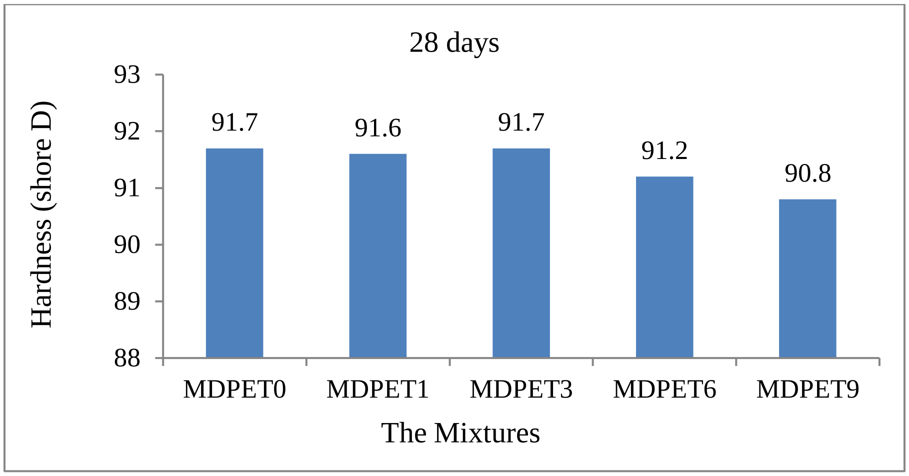


**Figure 5:** The Findings of Hardness Test.

*3.2* Findings of Ultrasonic Pulse Velocity (UPV) Test

The findings of UPV test of five composite mortar mixtures for standard age (28 days) are displayed in figure (6). From figures (6) the next findings can be noticed; that the cement mortar composite mixtures containing DPET particles (MDPET1, MDPET3, MDPET6 and MDPET9) have value of UPV lower than that of the reference cement mortar mixture without DPET particles (MDPET0). When DPET particles increases the UPV of the cement mortar composite reduces, and until to 9% which is maximum replacement that used in this study. At standard age (28 days) the UPV drops to the minimum value (3385 m/s) at MDPET9 that contains DPET particles of (9%). The maximum detraction in the UPV affecting of DPET particles of (9%), at 28 days was (-2.98%).

Through the above points, notice that the UPV that pass through the cement mortar composite was decreased with the DPET particles, this possibly because the fact of that the velocity of ultrasonic pulse transmission in a materials varies from one to another because the nature of each materials. So, seems that the DPET particles has ability to transmit ultrasonic pulse lower than that of sand, as a result the UPV in the modified cement mortar composite is low in compare with that of the reference cement mortar without DPET particles. In other hand, there is an opposite effect, the small size of DPET particles has was in the mortar supposed enable them to be located between the cement particles and this must increase the density of the mortar and thus increase the UPV, but seems that the effect of the low density in addition to low transmission of ultrasonic pulse of DPET particles has higher affected on the cement mortar composite.

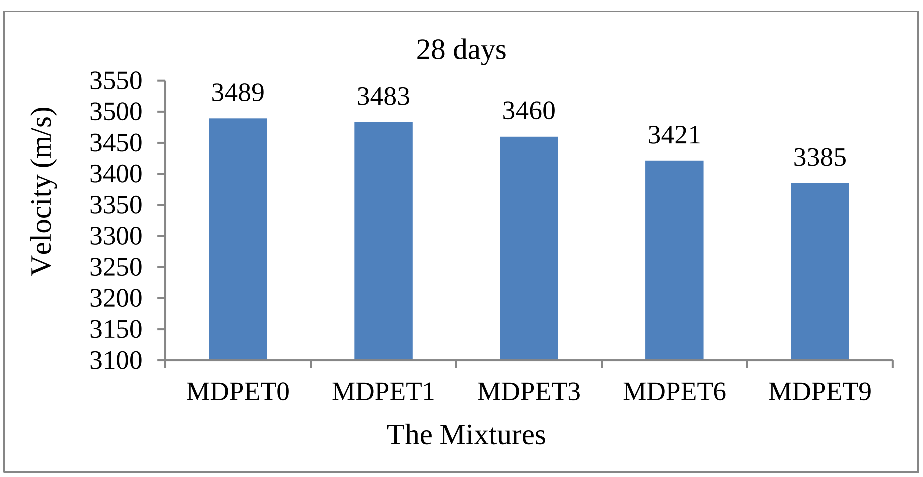


**Figure 6:** The Findings of UPV Test.

*3.3* Findings of Acoustic Insulation Test

The findings of acoustic insulation test of five composite mortar mixtures for standard age (28 days) are displayed in figure (7). From figures (7) the next findings can be noticed that all cement mortar composite mixtures containing DPET particles (MDPET1, MDPET3, MDPET6 and MDPET9) have acoustic insulation lower than that of the reference cement mortar mixture without DPET particles (MDPET0). Also, when DPET particles increase, the acoustic insulation of the cement mortar composite increases that until to 9% which is maximum replacement that used in this study.

Through the above points, notice that the acoustic insulation of the cement mortar composite was increase with the DPET particles, this possibly because the fact of that the acoustic insulation affected by the density of materials, so since the DPET particles has lower density than that of sand this mean the DPET particles have a tendency to slow the transmission of sound wave, which in turn increase the levels of sound lost across the cement mortar composite.

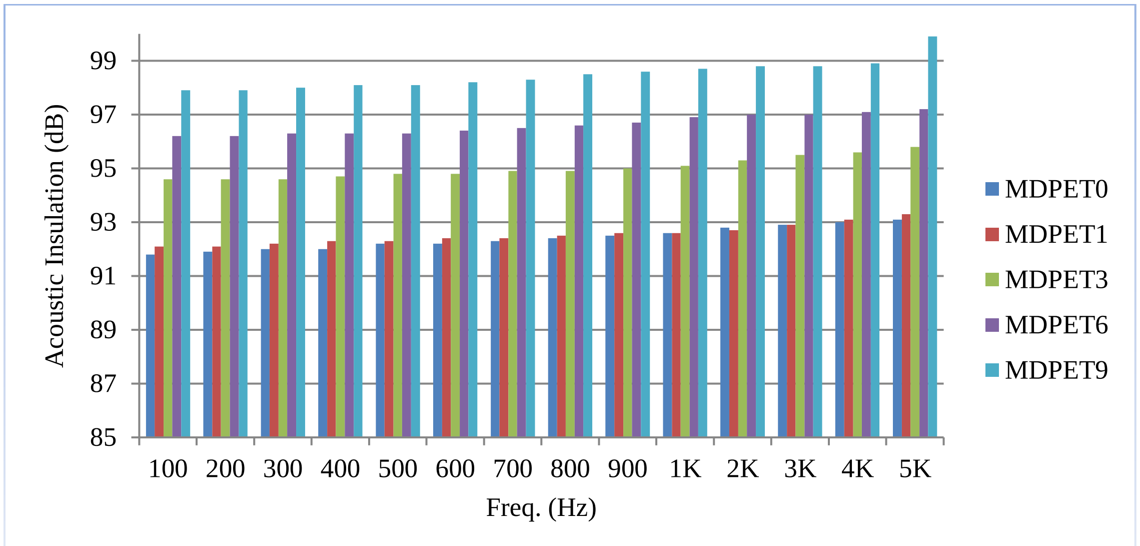


**Figure 7:** The Findings of Acoustic Insulation Test.

## 4. Conclusions

According to the experimental findings of the hardness, UPV and acoustic insulation tests, it was noticed that the DPET particles don't significantly affect the hardness of the cement mortar composite, while, the plastic DPET particles have a tendency to slow the transmission of ultrasonic pulse, which in turn decreases the overall UPV that pass through the cement mortar composite. Also, the DPET particles have a tendency to slow the transmission of sound wave, which in turn increase the levels of sound lost across the cement mortar composite.

The nature of DPET particles material which is different from that of sand enables DPET to decrease UPV and increase acoustic insulation. This is indicate that DPET particles which that made through depolymerized the PET of waste water bottles can enhancement the physical and insulating properties of the cement mortar. The findings concluded to that, using of waste materials after treatment process such as depolymerization in this study is better than using it directly as in other studies.

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