Compressive Strength and Electrical Properties of Cement Paste Utilizing Waste Polyethylene Terephthalate Bottles

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ABSTRACT

Plastics are among Billions of tons of non-hazardous solid waste material that are generated every year. With the scarcity of space for land filling, waste utilization has become an attractive alternative to disposal. Plastics are characterized by its low density, strength, light weight, and low cost, that made it a good material choice for utilizing in concrete and cement pastes. In this paper, the density and compressive strength of cement pastes utilizing plastics have been investigated. Moreover, effect of elevated temperature on the compressive strength was studied. Plastics were used in this study to replace the fine aggregate by weight using different percentages. The paper recommended utilizing plastics in cement paste with a percentage not greater than 10%. In the present work, dielectric and conductivity measurements in the frequency range of 0.1Hz – 5 MHz were carried out by means of a high resolution broadband spectrometer on cement paste filled with waste -PET samples, at various levels of hydration. The evolution of dielectric response was also examined after heating the samples up to 260°C. A useful end product cement paste characterized by its moderate electrical conductivity \( \sigma \) lies in the antistatic range (i.e. in the range \( 10^{-12} \) to \( 10^{-7} \)) was obtained.

Key words: Plastics, Cement Paste, Compression, Polyethylene terephthalate (PET), Fine Aggregate, dielectric properties, Conductivity.

Introduction

Plastic is one of the materials that are showing immense potential in our daily lives. Its low density, strength, user friendly designs, fabrication capabilities, long life, light weight and low cost are the factors behind such phenomenal growth (Siddique et al. 2008). Although, plastics have been used in very large and useful applications, it contributes to an ever increasing volume in the solid waste stream. In the plastics waste stream, polyethylene forms the largest fraction, which is followed by Polyethylene terephthalate (PET) (Subramanian, 2000).

Most plastics are non-degradable and take a long time to break down which significantly contributes to their environmental impact. With this tremendous increase in the plastic consumption, the landfill space required for the disposal of plastics wastes is a growing concern. With the scarcity of space for landfilling and due to its ever increasing cost, waste utilization has become an attractive alternative to disposal. Over the past two decades, research had been performed to study the availability of utilizing plastics in concrete mixes (Bayasi and Zeng, 1993, Al-Manaseer and Dalal, 1997, Soroushian et al., 2003, Choi et al., 2005, Batayneh et al, 2007 and Marzouk, 2007). The unique characteristics of plastics, being low density, light weight and low costs makes it a good material choice for utilizing in the concrete and cement pastes.

Hydration of cement paste is accompanied by changes in the water phase. Distinction between free water (e. g. in pores, or enclosed in cavities), adsorbed water and water of crystallization poses an experimental problem. With this increase in the plastic consumption, the landfill space required for the disposal of plastics wastes is a growing concern. With the scarcity of space for landfilling and due to its ever increasing cost, waste utilization has become an attractive alternative to disposal. Over the past two decades, research had been performed to study the availability of utilizing plastics in concrete mixes (Bayasi and Zeng, 1993, Al-Manaseer and Dalal, 1997, Soroushian et al., 2003, Choi et al., 2005, Batayneh et al, 2007 and Marzouk, 2007). The unique characteristics of plastics, being low density, light weight and low costs makes it a good material choice for utilizing in the concrete and cement pastes.

Hydration of cement paste is accompanied by changes in the water phase. Distinction between free water (e. g. in pores, or enclosed in cavities), adsorbed water and water of crystallization poses an experimental problem. The most obvious methods for distinguishing between free and bound water (vapor pressure, boiling point) fail in the ease of cement. Water of crystallization starts to evaporate from some Ca hydro silicates at 60 ~ while evaporation of free water from capillary pores is still very slow below 100 ~. In practice, the loss in weight after drying under arbitrary conditions is often taken as a measure of the quantity of "evaporable" water (McCarter et al., 1991)

There are various methods to study the cement paste hydration. The principal methods are X-ray diffraction (TAYLOR, 1990 Whittington et al., 1981), electron microscopy (Scrivener 1989) thermal analysis (Ben-dor and Perez, 1975), conduction calorimetry (Taylor, 1990) and electrical properties measurement (Li and Wei, 2003,
Gu et al., 1992, Gu et al. 1993, Coverdale, 1995), among which conduction calorimetry and the electrical methods are suitable to study the cement hydration. The electrical method can be used as an effective way to study the progress of cement hydration and to monitor structural changes occurring in the cement paste, mortar and concrete. During cement hydration, the water molecule in cement pastes or in mortars changes from free water to water bound in various states of hydration or crystallization. The electrical and dielectric properties of cement paste or mortar, such as ionic conduction, polarization ability, dielectric relaxation and dielectric loss, will change with hydration. Moreover, because a dipolar molecule changes from one bonding state to another, its ability to orient in an applied electric field changes. Thus, the changes in the dielectric constant and electrical conductivity during hydration will be related to the bonding state of cement paste, and therefore related to the changes of hydration products. The sensitivity of the dielectric constant and electrical conductivity to water content and the microstructure of cement paste and mortar suggest that these parameters should provide the information of cement hydration and can be used to monitor the hydration process in cement paste and mortars.

The main objective of this work is to prepare a cement paste characterized by antistatic properties. For this purpose the density, compressive strength, dielectric property and conductivity of cement pastes with/without waste PET have been investigated. Moreover, the effect of elevated temperature on the developed cement paste will be studied. Plastics have been used in this study to replace the fine aggregate by weight using different percentages.

**Material and Method**

**Materials:**

The material used to develop the cement paste mixtures in this study were cement, fine aggregate (sand), water, and plastic bottles. The cement used was Ordinary Portland Cement EN 197-1-CEM152.5N as per certificate of conformity CE – 0770 – CPD – C02/23. Natural sand having a fineness modulus of 2.31 was used as fine aggregate, and shredded plastic bottles made of polyethylene terephthalate (PET) were used as a replacement to the fine aggregate (Figure 1). The shredded bottles have a fineness modulus of 5.73.

![Shredded PET used in the concrete mix.](image-url)

Sieve analysis for the sand and the PET was performed according to the Egyptian Code of Practice (ECP 203-2003) to determine the gradation of these materials. PET was used to replace the sand by weight. Four percentages were used: 10%, 20%, 30% and 50% by weight of sand were replaced with PET. Figure 2 shows the sieve analysis results of the sand, PET, and the four percentages used.

**Dielectric properties Measurements:**

In the first set of measurements in solid cement samples, moisture was gradually removed from the samples by repeated drying cycles at 100 °C of various durations, between 10 and 60 min, depending on water content and dielectric spectra were recorded at room temperature immediately after each drying cycle. Gravimetric water content was determined by weighing the sample after each drying cycle, with an analytical balance of 0.001 mg accuracy. In the second set, solid samples with low water content were measured at room temperature after annealing to 260 °C, in order to determine the temperature effect on the dielectric response of the samples.
The samples were weighed before and after each measurement to insure that water content remained the same during the measurement.

![Sieve analysis of Sand and PET.](image)

These studies were carried out using an impedance analyzer (Schlumberger Solartron 1260), an electrometer, amplifier, and measuring cell as described before (Ward, 2003). Using the impedance analyzer, the permittivity \( \varepsilon' \), dielectric loss factor \( \tan \delta \), and ac resistance \( R_{ac} \) were measured at room temperature \( \sim 30^\circ C \) and different frequencies \( 0.1Hz - 5MHz \). The measurement was automated by interfacing the impedance analyzer with a personal computer through a GPIB cable IEE488. A commercial interfacing and automation software LabVIEW was used for acquisition of data. The error in \( \varepsilon' \) and \( \tan \delta \) amounts to 1% and 3%, respectively. The temperature of the samples was controlled by a temperature regulator with Pt 100 sensor. The error in temperature measurements amounts 0.5 \( ^\circ C \).

**Test setup and preparations:**

A total of 45 specimens were tested in this experiment. The specimens tested were cubes of dimensions 50 mm (Figure 3). The specimens were divided in five groups. A control group and four other groups, utilizing different percentages of PET as a replacement to sand in the cement paste (Figure 4). The specimens of the control group were designed as per Egyptian Code of Practice (ECP 203-2003) Annex three, guide for experimental testing of concrete materials. The control group and the first two groups, utilizing 10% and 20% of PET, respectively, were tested at three days, seven days and 28 days. Whereas, the third and fourth groups, utilizing 30% and 50% of PET, respectively, were tested at 28 days only. Moreover, the first and the second group, utilizing 10% and 20% of PET, respectively, were subjected to highly elevated temperature. Each group was subjected to a temperature of 300\(^\circ\)C and 500\(^\circ\)C, respectively, for 30 minutes. The 300\(^\circ\)C temperature is slightly higher than the glass transient temperature of PET, and it was chosen to study the behavior of the cement paste after the PET reaches the glass transient temperature. The 500\(^\circ\)C temperature is the temperature a normal concrete and cement paste can sustain as per specifications.

Table 1 shows the mixing proportions of tested specimens in each group, while Table 2 shows the number of specimens in each group, and the total number of specimens tested.

**Table 1: Mixing proportions of specimens.**

<table>
<thead>
<tr>
<th>Group No.</th>
<th>Percentage of PET by weight</th>
<th>Cement</th>
<th>Water</th>
<th>Sand</th>
<th>PET</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>G1</td>
<td>0</td>
<td>92.50</td>
<td>46.25</td>
<td>277.5</td>
<td>0</td>
<td>Control Group</td>
</tr>
<tr>
<td>G2</td>
<td>10</td>
<td>92.50</td>
<td>46.25</td>
<td>249.75</td>
<td>27.75</td>
<td></td>
</tr>
<tr>
<td>G3</td>
<td>20</td>
<td>92.50</td>
<td>46.25</td>
<td>222</td>
<td>55.50</td>
<td></td>
</tr>
<tr>
<td>G4</td>
<td>30</td>
<td>92.50</td>
<td>46.25</td>
<td>194.25</td>
<td>83.25</td>
<td></td>
</tr>
<tr>
<td>G5</td>
<td>50</td>
<td>92.50</td>
<td>46.25</td>
<td>138.75</td>
<td>138.75</td>
<td></td>
</tr>
</tbody>
</table>
Table 2: Number of specimens tested.

<table>
<thead>
<tr>
<th>Group No.</th>
<th>Tested Spec. at 3 days</th>
<th>Tested Spec. at 7 days</th>
<th>Tested Spec. at 28 days</th>
<th>Spec. subjected to 300°C</th>
<th>Spec. subjected to 500°C</th>
<th>Total no. of specimens Tested</th>
</tr>
</thead>
<tbody>
<tr>
<td>G1</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>--</td>
<td>--</td>
<td>9</td>
</tr>
<tr>
<td>G2</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>15</td>
</tr>
<tr>
<td>G3</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>15</td>
</tr>
<tr>
<td>G4</td>
<td>--</td>
<td>--</td>
<td>3</td>
<td>--</td>
<td>--</td>
<td>3</td>
</tr>
<tr>
<td>G5</td>
<td>--</td>
<td>--</td>
<td>3</td>
<td>--</td>
<td>--</td>
<td>3</td>
</tr>
<tr>
<td><strong>Total No. of specimens tested</strong></td>
<td><strong>--</strong></td>
<td><strong>--</strong></td>
<td><strong>--</strong></td>
<td><strong>--</strong></td>
<td><strong>--</strong></td>
<td><strong>45</strong></td>
</tr>
</tbody>
</table>

Fig. 3: Cement paste 50 mm cube specimens.

Fig. 4: Texture of specimen cast with different percentages of PET.

All the specimens were prepared as per Egyptian Code of Practice (ECP 203-2003) Annex three, guide for experimental testing of concrete materials. The cement pastes prepared were hand mixed. Sand, PET aggregate, and cement, were dry mixed together first, then the water was added on stages to the mix. Mixing of the paste continues until mixture became homogenous. Oiled steel cube molds of dimensions 50 mm, were filled, approximately, in three equal layers and compacted manually. After 24 hours of casting, the specimens were cured by soaking in to water until the day of testing. On the day of testing, the specimens were removed out from water and left to dry, weighed, and tested under compression loading using the universal testing machine.

It was observed during mixing the specimens that as the percentage of PET increases, mixing time to reach homogeneity of the mix increases. By reaching 30% of PET, complete homogeneity between the paste and PET was not achievable. Figure 4 compares two specimens, the one on the left utilize 50% of PET, and the one on the right utilize 10% of PET. It is very obvious from the figure that utilizing 50% of PET by weight in the cement paste will not be a practical solution.

From the above discussion, it was concluded that utilizing 30% of PET and more, by weight, in the cement paste is not a practical solution. Therefore, it was decided to postpone testing the specimens of groups four and five, utilizing 30% and 50% of PET, respectively, at three and seven days until finding out the compressive strength results of the test at 28 days.
Specimens subjected to elevated temperature were first cured for 28 days by soaking in water. The specimens were then removed from water and left to dry at room temperature for one day. On the next day, the specimens were placed in the furnace, the required temperature was adjusted, and the specimens were left for 30 minutes counted after the furnace reaches the required temperature. The specimens were then removed from the furnace, and left to dry for 24 hours, and then tested under compression using the universal axial loading machine.

Results and Discussion

The results of the average densities and compressive strength for control and PET specimens are shown in Table 3. Each of these results represents the average of three specimens.

It could be seen from the below table that there was a significant reduction in the density and compressive strength of cement paste for the fourth and the fifth group utilizing 30% and 50% of PET, respectively. Since the results of the compressive strength, at 28 days, of the fourth and fifth group were very low, it was decided not to test any more specimens at three or seven days for these groups and the conclusion of the impracticability of utilizing 30% and more of PET by weight in cement paste is confirmed.

Table 3: Values of test results.

<table>
<thead>
<tr>
<th>Group No.</th>
<th>Percentage of PET</th>
<th>Average density (g/cm³)</th>
<th>Average compressive strength (N/mm²)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>@ 3 days</td>
</tr>
<tr>
<td>G1</td>
<td>0</td>
<td>2.265</td>
<td>17.6</td>
</tr>
<tr>
<td>G2</td>
<td>10</td>
<td>2.166</td>
<td>17.40</td>
</tr>
<tr>
<td>G3</td>
<td>20</td>
<td>2.100</td>
<td>15.47</td>
</tr>
<tr>
<td>G4</td>
<td>30</td>
<td>1.757</td>
<td>Not tested</td>
</tr>
<tr>
<td>G5</td>
<td>50</td>
<td>1.370</td>
<td>Not tested</td>
</tr>
</tbody>
</table>

Moreover, it could be seen from the table, that the difference in the density and compressive strength of the control group and the second group, utilizing 10% of PET, is not significant. For the third group, utilizing 20% of PET, there was no significant difference in the compressive strength at three and seven days, respectively, compared to the control group. However, there was a significant difference in the compressive strength at 28 days, between the control group and the third group.

Cement Paste Density:

Figure 5 shows the effect of the PET replacement on the cement paste density. From this figure, it could be seen that as the percentage of PET in the mix increases the density decreases. This is because the density of PET is much less than that of sand. It could also be seen that there was a reduction of about 20% and 40% in the density of the specimens of the fourth and fifth group, respectively, compared to the control specimen. However, for the first and second group, the reduction was only 4% and 7%, respectively.

Fig. 5: Effect of the PET on the cement paste density.
Compressive Strength:

The effect of replacing PET with fine aggregate on the cement paste compressive strength is shown in Figure 6 and Figure 7. Figure 6 shows the effect of PET on the rate of strength gain with time, while Figure 7 shows the reduction percentage in compressive strength at 28 days of the different groups tested compared to the control group.

Fig. 6: Effect of PET on the compressive strength of cement paste.

It could be seen from Figure 6 that there is no significant difference in the rate of change of compressive strength for the control group and the second group, utilizing 10% of PET. However, there is a significant difference in the rate of change of compressive strength for the control group and the third group, utilizing 20% of PET. This means that increasing the percentage of PET in the cement paste affects the rate of change of compressive strength with time. Moreover, it could be seen from Figure 6 that the slope of the third group, utilizing 20% of PET, is very flat, with almost zero slope, while that of the control and the second groups are not. This indicates that, the rate of strength gain decreases as the percentage of PET increases. It could obviously be seen from Figure 6 that for the third group utilizing 20% of PET, the compressive strength at three days was 85% from the compressive strength at 28 days, and the compressive strength at seven days was 93% from the compressive strength at 28 days. Moreover, the compressive strength for the third group, utilizing 20% of PET, at 28 days was less than the compressive strength of the control group by about 40%. This means that the third group, utilizing 20% of PET, failed to achieve the required target compressive strength.

Fig. 7: Effect of PET on the compressive strength of cement paste.

Figure 7 show that there was a reduction of only 3% in the compressive strength of the first group, utilizing 10% of PET, compared to the control group. However, for the second, third, and fourth group, there was a reduction of 41%, 68%, and 91% in the compressive strength, respectively. This significant reduction in the
compressive strength is attributed to the difference in particle size, shape and surface texture of the sand and PET. Improper blend of aggregate influence the workability, compressive strength, and other properties of concrete and cement pastes, that is why ASTM C33 indicates that the fineness modulus of fine aggregate will not be less than 2.3 and not more than 3.1.

**Fig. 8:** Fineness Modulus of sand and PET.

Figure 8 compares the fineness moduli of the sand, PET, and the four percentages used. It could be seen from this figure that the fineness modulus of the fourth and fifth group, utilizing 30% and 50% of PET, exceeds the allowable limit of the ASTM C33, which explains why these groups gave unsuccessful compressive strength results.

**Effect of elevated temperature:**

The effect of elevated temperature on the compressive strength of cement paste utilizing PET is shown in Figure 9. This figure shows that there was a reduction of about 30% and 50% in the compressive strength of the cement paste, utilizing PET, after being subjected to an elevated temperature of 300°C and 500°C for 30 minutes, respectively. It could be concluded from this figure that the percentage of PET has no significant effect on the compressive strength of cement pasted subjected to elevated temperatures. Moreover, it could be seen from the figure that the rate of strength reduction is linear with the increase in temperature.

**Fig. 9:** Effect of elevated temperature on cement paste utilizing PET.
Dielectric Properties and electric modulus representations:

The real and imaginary part of dielectric permittivity ($\varepsilon'$ & $\varepsilon''$) of cement paste filled with different content of waste-PET at various water contents are shown in Figs [10-13] respectively. Large dispersions are observed, even for low water contents except for the dried sample in which real dielectric permittivity remains almost constant over the whole frequency range. The limit of $\varepsilon'$ at high frequencies $\varepsilon_\infty$ is 1.45 for dried sample and reaches the value of 7.4 for the sample with maximum water content, whereas that of water is approximately 80 at 20°C, in the MHz frequency range (Aragones, 2011).

The values of $\varepsilon'$ & $\varepsilon''$ were used to calculate the real ($M'$) and imaginary part ($M''$) of electric modulus (Sengwa et al., 2009):

$$
M'(\omega) = \frac{1}{\varepsilon'(\omega)} = M'(\omega) + iM'' = \frac{\varepsilon'}{\varepsilon'^2 + \varepsilon''^2} + i\frac{\varepsilon''}{\varepsilon'^2 + \varepsilon''^2}
$$

The advantage of complex electric modulus using is the variations in large values of the dielectric constant and conductivity at low frequencies are minimized [Uma Devi et al., 2002]. The real ($M'$) and imaginary part ($M''$) of electric modulus of cement paste samples, at several water contents is depicted in a semi-log scale as shown in Figs [10-13]b.

![Fig. 10: Dielectric property ($\varepsilon'$ & $\varepsilon''$) and electric modulus ($M'$ & $M''$) versus frequency ($f$) for cement paste measured at different hydration and at room temperature ~ 30°C.](image)

From these figures it is obvious that the real part of electric modulus ($M'$) increases with increasing frequency and water content, while a relaxation peak is developed in the $M''$ spectra is shifted to lower frequencies, as the water content decreases. Modulus spectrum of dried sample exhibits a low frequency peak and a loss peak at high frequency, probably due to water in a strongly bound state, which cannot be desorbed at the drying temperature of 100°C.
Fig. 11: Dielectric property ($\varepsilon'$ & $\varepsilon''$) and electric modulus ($M'$ & $M''$) versus frequency ($f$) for cement paste loaded 10 wt% Waste-PET measured at different hydration and at room temperature ~ 30°C.

Fig. 12: Dielectric property ($\varepsilon'$ & $\varepsilon''$) and electric modulus ($M'$ & $M''$) versus frequency ($f$) for cement paste loaded 20 wt% Waste-PET measured at different hydration and at room temperature ~ 30°C.
Fig. 13: Dielectric property (ε' & ε'') and electric modulus (M' & M'') versus frequency (f) for cement paste loaded 30 wt% Waste- PET measured at different hydration and at room temperature ~ 30°C.

The low frequency relaxation peak is attributed to the total conductivity of the measured samples, which appears as a steady increase of the dielectric loss while it is transformed in a loss peak in modulus representation. As the water content decreases, conductivity peak is shifted to lower frequencies, which is translated to a lower contribution of conductivity term to dielectric losses. The high frequency relaxation peak, observed in modulus representation at f > 10⁵ Hz and water content greater than 3.5%, is due to the polarization of bound water. Relaxation processes due to bound water states have been reported to appear in the megahertz region or even at lower frequencies, depending on the state of bound water (strongly or weakly bound) and its concentration (Nettelblad and Niklasson, 1997, Cadène, 2006).

Figure 14 shows the permittivity of four ratios PET -waste filled cement paste, each at fixed frequency 100Hz. For any type of cement paste, the permittivity ε' decreases with decreasing water content, as expected. At any point, the permittivity ε' decreases by the addition of PET -waste. The further addition of PET -waste appears to have a small effect on the permittivity of cement paste. However, at low water content we found that PET –waste (10%) increases the permittivity of cement paste. Our observation regarding the effect of PET -waste can be due to the decrease of air voids and cement porosity (Hughes et al., 1985), as the incorporation of PET-waste is expected to decrease the air voids content, and air voids tend to decrease the permittivity. In other words, a decrease in air voids content is expected to increase the permittivity. So we attribute the decrease of the permittivity by the further addition of PET-waste to the increase air void content due to its bad dispersion in the cement matrix. These results are greatly support the results of compressive strength.

The variation of dc-conductivity (σdc) measured at versus water content is shown in Fig. [15] in a semi-log scale. It exhibits a third order polynomial behavior, indicative of contribution of different mechanisms to the measured conductivity, where the absorbed water plays a crucial role. More specifically, bound water in smectite consists of interlayer water, which is held between the layers of the quasi-crystals, and water, adsorbed on the external surfaces of the quasi-crystals. It has been reported by Logsdon that, interlayer water is stronger bound, exhibiting a lower relaxation frequency than surface water (Logsdon and Laird, 2002). From the same figure, it is interesting to notice that after 28 days, where the paste reaches its characteristic compressive strength and at water content ~11%, the paste was characterized by electric conductivity lies in the order of (10⁶
According to these values of electric conductivity, these samples may be considered as antistatic materials which should be in the order (i.e in the range $10^{-12}$ to $10^{-7}$ S/m) (Huang, 2002).

**Fig. 14:** Variation of permittivity $\varepsilon'$ of cement paste loaded with PET-waste versus water content.

**Fig. 15:** Variation of dc-conductivity of cement paste loaded with PET-waste versus water content.

**Effect of elevated temperature on the dielectric properties:**

The effect of temperature on dielectric properties of cement paste samples containing ~ 0% hydration is illustrated graphically in Figure 16. From this figure it is clear that the value of the real and imaginary part of dielectric permittivity of cement paste filled waste-PET increased after heating the samples up to 260°C. As this temperature is quite enough to melt PET, so it is expected a decrement in the number of pores/air voids which is the mean reason of lower dielectric permittivity. The photographs of the samples before and after heating are shown in figure 17.
Fig. 16: Dielectric property ($\varepsilon'$ & $\varepsilon''$) versus frequency $f$ for:
(a). low water content (0%) cement paste loaded with different ratios of Waste-PET at 30°C.
(b). low water content (0%) cement paste after heating up to 260°C.

Fig. 17: Photographs of cement paste-10% Waste-PET.
(a) before heating
(b) after heating up to 260°C
Conclusion:

This paper presented the effect of PET on the density and compressive strength of cement paste mixtures. PET was used as a replacement to fine aggregate in the mix with different percentages. The effect of elevated temperature on the compressive strength of the cement pastes, utilizing PET, was also studied in this paper. From the results of this study, the following conclusions and recommendation are drawn:

1. There was a reduction of about 4% and 7% in the density of cement paste utilizing 10% and 20% of PET, respectively. The reduction was significantly increased by increasing the percentage of PET in the cement paste.
2. Although there was a significant reduction in the density of cement paste utilizing 30% and 50% of PET, there was a significant reduction in the compressive strength as well. This significant reduction in the compressive strength weakens its application in the civil engineering field.
3. The rate of strength gain with time decreases as the percentage of PET increases.
4. There was no significant increase in the compressive strength of the cement paste utilizing 20% of PET after seven days of casting.
5. There was a slight reduction of 3% in the compressive strength of the cement paste, utilizing 10% of PET, compared to the control one. However, the reduction was 41%, 68%, and 91%, when utilizing 20%, 30% and 50% of PET, respectively.
6. There was a reduction of about 30% and 50% in the compressive strength of the cement paste, utilizing PET, after being subjected to elevated temperature of 300°C and 500°C for 30 minutes, respectively.
7. The rate of strength reduction is linear with the increase in temperature.
8. It is recommended to perform more experiments to fully investigate the compressive strength of cement paste utilizing PET.
9. Cement paste utilizing 10% of PET shows satisfactory compressive strength results, and therefore, it is recommended to be used in civil engineering applications to save the environment.
10. It is recommended to perform more experiments to study the flexural and tensile strength of cement pastes utilizing PET.
11. It is recommended to try the same experiment, yet replacing the weight percentage of sand by volume percentage of sand.
12. PET/Cement paste looks like marble when heated at 260°C so it can be also used in constructions of small drainage works and concert tiles of foot path walkers.
13. the partial replacement of PET-Waste also helps to avoid the general disposal technique of waste plastic namely land filling and incineration which have certain burden on ecology.
14. We have also measured the dielectric properties and electrical conductivity of cement paste with different Waste –PET concentration (0, 10, 20 and 30%) at room temperature and at different water content in the frequency range 0.1Hz -5MHz. We found that both dielectric properties and electrical conductivity are sensitive to the water-cement ratio (w/c). The higher the w/c value, the greater were the values of permittivity $\varepsilon'$, dielectric loss $\varepsilon''$ and electrical conductivity. The frequency effect on dielectric properties was also studied. We found that the higher the frequency, the smaller were the permittivity $\varepsilon'$, dielectric loss $\varepsilon''$.
15. The influence of the PET waste on the hydration level on the dielectric response of cement pastes. Utilizing 10% of Waste –PET, compared to the control one the, results shows good dielectric properties due to the decrease in the cement paste porosity.
16. According to the values of electric conductivity these materials could be used for antistatic applications.

References


