# The impact of Cement Mortar Reinforced with Recycled Polyethylene for Construction Applications in Tropical Regions

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## Abstract

This current research work combines both experimental and theoretical study of the impact of cement mortar reinforced with recycled polyethylene for applications in the tropical regions. The work explores incorporating low density polyethylene (LDPE) waste into cement mortar to improve its fracture toughness and flexural strength with balanced compressive strength. Different volume fractions (0, 5, 10, 15, 20, 30, and 40 %) of the powdered LDPE were mixed with cement and the density, compressive strength, flexural strength, and the fracture toughness were observed under different testing conditions. All specimens were tested after curing of 7, 14, and 28 days. The results show that there was ~6 % increase in the fracture toughness at 5 vol. %, ~7 % increase at 10 vol. %, and 24 vol. % increases at 20 vol. % of LDPE. Also, it was observed that the weight and compressive strength decreased with increasing volume fraction up to 40 vol. % of LDPE waste. The results for the survival/failure probability show that the PE-mortar composites with PE volume percentages up to 20 vol. % had the highest survival probability. The composite with this volume percentage can withstand crackup to 7 mm, with a survival probability of 0.6.

**Keywords:** Polyethylene; Survival/Failure probability; Brittle fracture modelling, Mechanical testing; Crack opening tip displacement

# 1 Introduction

The collapse of buildings poses major challenges and threats to the health and wellbeing of the human race worldwide. Over time, major damages have been reported resulting in expansive loss of huge investments in housing and properties (Blunden 2016), with many people losing their lives. In most cases, people have sleepless nights and state of unrest. The world is, however, relatively unstable as a result of the geometrical order of population growth, urban development in coastal areas, poor planning and housing developments in high risk areas of cities (Davy 2009).

Furthermore, researchers and engineers throughout West Africa have shown that building collapses occurs to a diversity of factors (Opara 2007). Some of these factors include but not limited to employment of incompetent artisans (Opara 2007; Michael and Razak 2013), weak work supervision of workmen at building sites, endemic poor work ethics and non-enforcement of existing laws (Opara 2007; Michael and Razak 2013). Research carried out by Michael and Razak (2013) showed that cases of building collapse are not restricted by climatology or level of urbanization since these cut across cultural and ethnical barriers. Additionally, other main causes and major challenges have being attributed to non-compliance with specifications standards a well as using of sub-standard building materials and equipment (Yilidirim and Sengul 2011; Siegel et al. 2013). In line with this non-compliance or use of sub-standard material, the type and quality of cement used in concrete structures plays a significant role in building and constructions. Furthermore, concrete ability to withstand certain loads has significant impact on its durability. There is, therefore a need to investigate the quality of materials used in making the concrete for construction in the Africa and the world at large (Siegel et al. 2013).

Globally, Cements often used as binders are very expensive for the construction of modern buildings. This binder is not environmental friendly and therefore, there is the need to substitute whole or part of this polluting cement with materials that can be recycled. Recently, a couple ofworks have been carried out to fully or partially replace industrial cement with several natural and artificial wastes (Tonoli et al. 2007; Setién et al. 2009; Terzietć al. 2013; Bouasker et al. 2014; Gesoğlu et al., 2014; Mustapha et al. 2015; Azeko et al. 2016a; Azeko et al. 2016b; Mustapha et al. 2016; Azeko et al. 2018) for composite processing in building applications. These recycled materials including polyethylene (Azeko et al. 2016a) and natural straws (Mustapha et al. 2015) in cement have shown to possess excellent compressive strengths, flexural strengths, fracture toughness, and erosion resistance that are comparable to cement-based structures produced from sea/river sand.

Although these research methods have greatly influenced the mechanical and physical properties of reinforced bricks/blocks, there is still the need to provide more insight into the solving of cracking and failure associated problems in the building and construction industries. This work therefore recycled waste polyethylene into pellets and mixed with cement mortar to produce polyethylene-cement composites in different proportions for sustainable building applications.

# 2 Modelling

## 2.1 Modeling of Brittle Fracture

Assuming linear elastic fracture mechanics (LEFM) conditions are applicable in polymer- reinforced composites, the stress distribution, $\sigma_{ij}$ ahead of a crack that is dominant and causes failure in these composites could be estimated from (Azeko et al. 2016b):

$$\sigma_{ij} = \frac{K_I}{\sqrt{2\pi r}} f(\theta) \quad (1)$$

where $K_I$ is the stress intensity factor, while r and θ are the polar coordinates from the crack-tip, and $f(\theta)$ depends on the mode of loading (Azeko et al. 2016b). Also, assuming that the distribution of size of the plastic reinforcement can be compared to the distribution of size of inclusions ahead ofthe crack-tip, then the indigenous circumstances for interfacial cracking de-cohesion can be expressed as (Azeko et al. 2016b; Soboyejo 2007):

$$\sigma_c = \frac{\pi E_m G_m}{(1-v_m^2)\, d_c} \tag{2}$$

where $E_m$ represents the Elastic/Young's modulus of the matrix, $G_m$ is the matrix fracture energy, $v_m$ is the matrix poison's ratio, whereas d is the critical diameter of the particle. Since the disparities in the particle sizes are known from experiments, the discrepancies in the particle strengths can be related directly to the variations in particle strength.

Furthermore, the puniest link statistics could be used to determine the probability of failure or survival within the fracture process zone. The probability of failure within the process zone is expressed as (Soboyejo 2002; Fashina et al. 2017):

$$\Delta\phi = 1 - \exp\left[-\Delta v \int_0^s g(\sigma)d\sigma\right] \tag{3}$$

Where $\Delta v$ the incremental volume, g is represents the strength distribution, σ denote the strength and s is the applied stress. Therefore, survival probability is given by:

$$\Phi = 1 - \exp\left[-\int_0^v dv \int_0^s g(\sigma)d\sigma\right] \tag{4}$$

where v is the volume of the process zone and g(σ)dσ is the elemental strength distribution proposed by Weibull (Weibull 1951) and given by (Azeko et al. 2016b) to be:

$$\int_0^s g(\sigma)d\sigma = \left(\frac{s - s_u}{s_0}\right)^m Z_f N_1 \tag{5}$$

where mis the Weibull modulus or shape parameter, $S_u$ is the particle strength of lower bound, $Zf$ is the fraction of particles that partakes in the fracture process and $N_I$ is the number of particles in one unit volume. Therefore, since the size distribution of particles is known with the stress distribution within the process zone, the failure probabilities can be calculated directly from equations 5. In the case of brittle fracture under linear elastic fracture conditions, the failure probability for linear elastic conditions can be obtained by applying the Hutchinson-Rice- Rosengreen (HRR) conditions. From the HRR approach, the crack-tip field is given by:

$$\frac{s_{ij}}{s_{ys}} = \left[\frac{EJ}{\alpha s_{ys}^2 I_n r}\right]^{\frac{1}{n+1}} \tilde{s}_{ij}^{\,n+1}(n,\theta) \tag{6}$$

where E represents the Young's modulus, J is the J integral, $S_{ys}$ denote the yield stress, n is the strain hardening exponent and $I_n$ is a constant of integration dependent on n and stress state. If we now assume that weak link statistics prevail, the survival probability in the elemental volume is given by (Weibull 1951):

$$P_s\left(\bar{s}_i\right) = \exp\left[-\Delta v_i \left(\frac{\bar{s}_i - s_u}{s_0}\right)^m\right] \tag{7}$$

where $\Delta v_i$ is the volume of the plastic zone, $s_u$ represents the lower bound strength , $s_o$ is the mean strength and $\bar{s}_i$ is the annular element average stress component. When $\Delta v_i$ is close to zero, the average stress is equal to s atr.

If we now assume that the survival probability in the first annular element is regarded as $P_1$ and the second annular element is $P_2$ and soon, then one can estimate the survival probability in the fracture process zone with z annular volumes as

$$P_s(z) = P_s(1).P_s(2).P_s(3)...P_s(z) \tag{8}$$

Therefore, substituting equation 7 into 8 yields:

$$P_s(z) = \prod_{i=1}^{z} \exp\left[-\Delta v_i\left(\frac{s_i - s_u}{s_o}\right)\right]^m \tag{9}$$

Equation 19 can be simplified andre-written as:

$$P_s(z) = \exp\left[-\Delta v_i \sum_{i=1}^{k}\left(\frac{s_i - s_u}{s_o}\right)^m\right] \tag{10}$$

Hence, the Total Survival Probability can now be expressed in integral form as:

$$P_s(r) = \exp\left[-2B\beta fN\int_0^{\pi}\int_{r_o}^{r_p}\left(\frac{s - s_u}{s_o}\right)^m rdrd\theta\right] \tag{11}$$

where $r_o$ is the radial distance at which HRR stresses are truncated by crack-tip blunting and $r_p$ is the plastic zone size which is given by:

$$r_p = \lambda\left(\frac{K_I}{s_{ys}}\right)^2 \tag{12}$$

where $K_I$ is the stress intensity factor and $S_{ys}$ is the yield stress. The crack tip opening displacement (CTOD), $\Delta$, is given by:

$$\Delta = d_n s_{ys} K_I^2 / E' \tag{13}$$

where $E' = E/(1\text{-}v^2)$ for plain strain conditions and $E' = E$ for plane stress conditions. The parameter $d_n$ is given by:

$$d_n = 2\tilde{\mu}_{ij}(\pi,n)\left[\frac{\alpha s_y}{E'}\left(\tilde{\mu}_x(\pi,n) + \tilde{\mu}_y(\pi,n)\right)\right]^{\frac{1}{n}} \tag{14}$$

where $\tilde{\mu}_x$ $(\pi, n)$ and $\tilde{\mu}_y$ $(\pi, n)$ are functions of n, and the other constants have their usual meanings. Using atypical value of dn of 0.5 and substituting equation 13 into 12 gives:

$$r_p = \lambda \frac{E\delta}{d_n(1-\nu)s_{ys}} \tag{15}$$

Hence, the total failure probability, $\Phi$, is given by (Azeko et al. 2016b; Soboyejo 2007):

$$\Phi = 1 - P_s(r) = 1 - \exp\left[-2B\beta fN \int_0^{\pi}\int_{r_o}^{r_p}\left(\frac{s-s_u}{s_o}\right)^m r dr d\theta\right] \tag{16}$$

# 3 Experimental Procedures

## 3.1 Production of Low Density Polyethylene Pellets

Waste water sachets classified as linear low density polyethylene found littering everywhere were collected in huge quantity from streets, market place, dumpsite, etc. Detergents such as tween 80 and sodium dodecyl sulphate were used to wash the water sachets to remove microbes and other dirty substances. The plastics were then dried in the sun for about two hours to remove moisture. A hot plate was plugged to provide heat. Kerosene was placed on the hot plate. It was heated for about one hour thirty minutes until it reached its initial boiling temperature of 140 ℃. (Azeko et al. 2016a). The plastics were then melted in the kerosene until they completely dissolved and formed a viscous liquid. The polymer's long chains were broken down upon heating at its melting temperature. The viscous liquid was rapidly quenched/ cooled in a block of ice at a temperature of between -6 ℃ and -8 ℃. After it was rapidly cooled and squeezed to remove traces of kerosene, the slurry was washed severally with ethanol and acetone and squeezed to further remove traces of kerosene. The powder particles were dried in the sun for 24 hours and the plastic pellets obtained in different sizes by sieving.

## 3.2 Composite Processing by Volume fraction

During the preparation of the cement mortar/composite, two different types of samples were prepared - the one without the polyethylene labelled DM/0.00 and the one with the polyethylene labelled DM/c, where c represent the volume percentages of polyethylene (PE) that partially replaced certain percentage of sand. The volume percentages of polyethylene pellets used were 0%, 5%, 10%, 15%, 20%, 30% and 40%. The different percentages of PE pellets were then casted into a mould with dimensions 40 × 40 × 160 $cm^3$ with mix ratio was 2:1:6 as described by (Davy 2009) [2]. Mixing of concrete and compaction of the blocks was done mechanically. The prepared mortars were packed on boards for 24 hours before curing started.

## 3.3 Properties of Dangote 3X Cement

According to the standard organization of Nigeria, the Dangote 3X cement also known as extra life and extra yield is the latest version of cement produced by the Dangote cement company in few countries across West Africa such as Nigeria and Ghana. This cement produces a high quality with 42.5 grades. According to Oare Ojeikre, Group Chief Marketing Officer of the Dangote group, this 42.5 R grade cement coupled with the unveiling of a new product (42.5 3X), with the recent maelstrom surrounding the ban of the 32.5 grade cement because of its low grade.

Moreover, this new cement has unique mechanical properties that slightly distinguish it from other cement. For example, unlike other cement (32.5, Portland), the Dangote 3X provides extra strength and rapid drying property which makes the product the first choice for builders and contractors. Furthermore, a bag of the new Dangote 3X Cement - 42.5R variety is observed as equivalent to one and half bag of the regular cement bag.

In terms of Xtra Life, it is speculated that 42.5 is ground finer than 32.5, giving a finer finish to concrete work, adding that the mixed cement has fewer air-pockets and therefore, adheres better and has longer life. Because of its higher strength characteristics, it is believed that 42.5 grade cement gives users higher yield than 32.5 in situations where strength is not a crucial factor, for ordinary applications, cement users could mix more sand into the same quantity of 42.5 cement, thus increasing the volume and making more blocks. Its setting characteristics is said to be rapid (R) as against others that are normal (N). This 42.5R cement is has a tendency to set more rapidly than 42.5N cement. For example, if 'N' reaches a strength level of 10 MPa in two days, 'R' would reach 20 MPa in the sametime.

## 3.4 Mechanical Testing

The composite samples produced with or without the polyethylene were subjected to different mechanical testing such as compressive/flexural strengths and fracture toughness. A universal mechanical testing machine (TIRAtest model 2810, Schalkau, Thuringia, Germany) was used for the compressive/flexural strength and fracture toughness measurement. The compressive/flexural tests were carried out using a displacement rate of 0.05 mm/s and a strain

rate of 0.05/s. The samples were loaded monotonically using a load cell of 25 kN until failure occurred in the samples.

The flexural strength was calculated from the expression $\sigma = \frac{3}{2}\left(\frac{LF}{BD^2}\right)$ (17)

where σ is the flexural strength (N/mm$^2$), L isthe loading span in mm), F is the maximum applied load (N), B is the average width of the specimen (mm), and D is the average thickness (mm) [13].

For each of the specimen, where $\sigma_c$ is the critical applied stress, f (a/w) is a function of the crack length, $a_c$ is the critical crack length and W is the width of the specimen/component, the fracture toughness is given by (Azeko et al. 2016a):

$$K_c = F(\frac{a}{w})\sigma_c\sqrt{\pi a_c} \quad (18)$$

The values of the compressive strength of the mortar were compared to that of the European standard for the requirement of compressive strength for various curing time given in the Table 2

# 4 Results and Discussions

The results for the compressive strengths, flexural strengths and fracture toughness values are shown in Tables (2-5) and Figures (2-5). It was realized that, the compressive strengths for the different samples increases as the number of days increases until the maximum compressive strength is attained at day 28 (Table 3). This is possible because the cement in the composite takes at least 21 days for complete hydration. The complete hydration of cement increases the bond strength in the composite and this therefore, increases the overall compressive strengths in the composite. However, the average weights of the samples decreases as the number of days increases as illustrated in Figure 2 and Table 3. The results showed that the weight of the mortar

decreased with increasing volume percentages of PE up to 40. This is associated with the dehydration of water molecules by cement, enabling cement to be completed hydrated.

The results for the trends in compressive strengths are shown in Table 3 and Figure 3. It is seen that the compressive strength for the composite without the inclusion of polyethylene was tremendously higher than the composites with different volumes of polyethylene for the first one week. However, as the number of weeks increases to the maximum weeks of four, the difference in the compressive strengths of composite without PE inclusion and composite with PE inclusions for volume percentages from 5 % up to 15 % was comparably small. This is because; at day 28, the composite with PE inclusions had completely cured and the bond strength between the cement and the PE attained its maximum strength. Since the primary idea for the inclusion of PE in the composite is to help in bridging or shielding cracks/micro-cracks, higher bond strength co- existing between the mortar and the PE leads to overall compressive strengths in the composite.

The results for the flexural strengths and fracture toughness values for the different composite composition are presented, respectively, in Figure 4 and Figure 5. It is observed that the flexural strengths for the composite with PE inclusions from 5 % up to 20 % are higher than the mortar without PE inclusions (Figure 4). The polyethylene (PE) is responsible for such behaviour in the composite. The availability of PE in the composites facilitates the shielding of micro-cracks, resulting in the overall strength of the composite. However, the composite with PE inclusions of more than 20 % recorded lower flexural strengths as compared to the cement mortar without PE. This is attributed to the fact that more PE pellets causes agglomeration and creates a weak linkage between PE-PE particles/pellets surface interactions.

The fracture toughness values of the composite increases with increasing curing time up to the maximum of 28 days (Figure 5). Also, the fracture toughness values increases with the inclusion of PE pellets in the mortar for PE volume percentages of 5 % up to 20 % and then decreases with PE volume percentages of more than 20 % and beyond. Again, the presence of many PE pellets/particles in the composites causes agglomeration and this creates a weak interface between PE-PE particles interactions, which has an overall effect in the fracture toughness of the resulting composite.

Flexural strength measures the strength of concrete due to bending/bending moments by mostly applying a three-point loading. Cementitious materials are generally known to be strong in compression but poor in tension because the bonds formed cannot be stretched beyond their limits. The materials used to make the mortar are mostly brittle and fracture upon tensile loading. Flexural Strength of Concrete is about 10 to 20 percent of compressive strength depending on the type, size and volume of coarse aggregate used (Setién et al. 2009). The polymer when deformed elastically can return to its normal shape. Therefore, the presence of the polymer in the mortar helped to improve its ductility. Furthermore, the flexural strength and fracture toughness increased up to 20% of the polymer before it started to decrease. This is also because the high tensile strength of the polymer in Table 6 contributed to the increase in the flexural strength and fracture toughness of the mortar.

The results for the reliability analysis of the different volume percentages of PE-mortar composites are illustrated in Figures 6 and 7. It is clearly shown that the PE-mortar composites with PE volume percentages of 20 % had the highest survival probability (Figure 6). The composite with this volume percentage can withstand crack up to 7 mm, with a survival probability of 0.6. At this probability, the composite is still strong enough to carry the required load on it. Also, this composite with PE volume percentage of 20 % can survive up to a crack extension of 16 mm, before final failure occurs at exactly crack propagation of 18 mm (Figures 6 and 7). Composites with PE volume percentages of 10 % and 15 % performed fairly well as far as survival and failure of the composite is concerned as illustrated in Figures 6 and 7.

## 5 Conclusion

This research presented a mechanistic approach of how to recycled LDPE waste into useful materials for building applications in tropical countries. This mechanism allows us to minimize environmental degradation and also its hazardous impacts (land pollution, health risks, etc.). According to this research, the use of such waste polyethylene materials in mortar helped to lower the weight of the material by ~8 % at

5 vol. % PE; ~12 % at 10 vol. % PE, and ~29 % at 40 vol. %. This means that these different decreased percentages at various increased in the PE can be used for different applications for the manufacturing of slabs, designer column, beam, parapets, etc.

Additionally, the presence of the PE in the mortar decreased the compressive strength by 8.2 at 5 vol. % PE, 12 % at 10 vol. % PE, 15 % at 15 vol. % PE, and 48 % at 40 vol. % PE due to inadequate bonding between the cement paste and the PE. However, 5 %, 10 %, 15 % and 20 % met the maximum compressive strength requirement for concrete/mortar after 28 days. As the objective of the work was concerned, the flexural strengths, fracture toughness of the mortar increased as the volume percentage of PE increased up to values of 20 vol. %. This implies that instances where the materials needed to be strong and tough, these different percentages could help designers to make the right choice(s).

It is clearly shown that the PE-mortar composites with PE volume percentages of 20 % had the highest survival probability (Figure 6). The composite with this volume percentage can withstand crack up to 7 mm, with a survival probability of 0.6. At this probability, the composite is still strong enough to carry the required load on it. Also, this composite with PE volume percentage of 20 % can survive up to a crack extension of 16 mm, before final failure occurs at exactly crack propagation of 18 mm (Figures 6 and 7). Composites with PE volume percentages

of 10 % and 15 % performed fairly well as far as survival and failure of the composite is concerned as illustrated in Figures 6 and 7.

## Data Availability Statement

The data for this research will be made available upon request.

## Acknowledgement

The authors are grateful to Tamale Technical University and the University of Ghana for their financial support

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Table 1: Representation of Samples by Volume Fraction

| Sample | Water(g) | Cement(kg) | Sand(kg) | Polymer(kg) |
|---|---|---|---|---|
| DM | 225 | 450 | 1350 | 0 |
| DM/0.05 | 225 | 450 | 1282.5 | 67.50 |
| DM/0.10 | 225 | 450 | 1215.00 | 135.00 |
| DM/0.15 | 225 | 450 | 1147.5 | 202.5 |
| DM/0.20 | 225 | 450 | 1080.00 | 270.00 |
| DM/0.30 | 225 | 450 | 945.00 | 405.00 |
| DM/0.40 | 225 | 45 | 810.00 | 540.00 |

Note: DM/0.00=Sample with 0 % PE; DM/0.05=Sample with 5 % PE; DM/0.0=Sample with 10 % PE; DM/0.15= Sample with 15 % PE; DM/0.20=Sample with 20 % PE; DM/0.30=Sample with 30 % PE. DM/0.40=Sample with 40 % PE

Table 2: European Standard for Compressive Strength (EN97 -1)

| Strength class | Compressive strength(MPa) | | | | Initial setting time(min) | Soundness expansion in mm |
|---|---|---|---|---|---|---|
| | Early strength | | Standard strength | | | |
| | 2days | 7days | 28days | | | |
| 32.5N | - | ≥16.0 | ≥32.5 | | ≥75 | |
| 32.5R | ≥10.0 | - | | ≤52.5 | | |
| 45.2N | ≥10.0 | - | | | ≥60 | **≤10** |
| 45.2R | ≥20.0 | - | 42.5 | ≤62.5 | | |
| 52.5N | ≥20.0 | - | 52.5 | | ≥40 | |
| 52.5R | ≥30.0 | - | | - | | |

Note: DM/0.00=Sample with 0 % PE; DM/0.05=Sample with 5 % PE; DM/0.0=Sample with 10 % PE; DM/0.15= Sample with 15 % PE; DM/0.20=Sample with 20 % PE; DM/0.30=Sample with 30 % PE. DM/0.40=Sample with 40 % PE

Table 3: Average Weights and Compressive Strengths for Sample Tested

| Average weight (kg) versus compressive strength(($N/mm^2$) | | | | | | |
|---|---|---|---|---|---|---|
| **Sample Identification** | **Day 7** | | **Day 14** | | **Day 28** | |
| | Weights | Compressive strengths | Weights | Compressive strengths | weights | Compressive strengths |
| DM/0.00 | 586.60 | 39.80 | 583.20 | 41.60 | 580.12 | 50.40 |
| DM/0.05 | 559.00 | 20.40 | 534.50 | 37.66 | 532.56 | 46.22 |
| DM/0.10 | 543.13 | 18.95 | 519.43 | 35.01 | 510.00 | 44.34 |
| DM/0.15 | 531.15 | 18.33 | 506.58 | 34.35 | 504.00 | 43.03 |
| DM/0.20 | 510.14 | 18.01 | 485.11 | 29.37 | 483.00 | 42.19 |
| DM/0.30 | 496.67 | 17.12 | 471.01 | 20.28 | 469.00 | 30.23 |
| DM/0.40 | 440.12 | 16.53 | 415.12 | 17.21 | 413.09 | 26.33 |

Note: DM/0.00=Sample with 0 % PE; DM/0.05=Sample with 5 % PE; DM/0.0=Sample with 10 % PE; DM/0.15= Sample with 15 % PE; DM/0.20=Sample with 20 % PE; DM/0.30=Sample with 30 % PE. DM/0.40=Sample with 40 % PE

Table 4: Values of Maximum Compressive Load at Fracture

| Average maximum Compressive load strength(N) | | | |
|---|---|---|---|
| Sample | Day 7 | Day 14 | Day 28 |
| DM/0.00 | 209.03 | 281.05 | 335.80 |
| DM/0.05 | 215.51 | 293.04 | 358.23 |
| DM/0.10 | 229.01 | 330.01 | 400.20 |
| DM/0.15 | 232.58 | 333.79 | 420.36 |
| DM/0.20 | 235.58 | 337.23 | 422.5 |
| DM/0.30 | 161.54 | 255.84 | 330.43 |
| DM/0.40 | 154.52 | 242.05 | 320.58 |

Note: DM/0.00=Sample with 0 % PE; DM/0.05=Sample with 5 % PE; DM/0.0=Sample with 10 % PE; DM/0.15= Sample with 15 % PE; DM/0.20=Sample with 20 % PE; DM/0.30=Sample with 30 % PE. DM/0.40=Sample with 40 % PE

Table 5: Average Flexural Strengths and Fracture Toughness Values

| Average flexural strength(N/mm$^2$) versus Fracture toughness(**MPa$\sqrt{m}$**) | | | | | | |
|---|---|---|---|---|---|---|
| Sample | **Day 7** | | **Day 14** | | **Day 28** | |
| Id | Flexural strengths | Fracture toughness | Flexural strengths | Fracture toughness | Flexural strengths | Fracture toughness |
| **DM/0.00** | 1.43 | 2.08 | 1.92 | 2.79 | 2.30 | 3.35 |
| **DM/0.05** | 1.47 | 2.14 | 2.01 | 2.92 | 2.45 | 3.57 |
| **DM/0.10** | 1.57 | 2.28 | 2.26 | 3.28 | 2.47 | 3.59 |
| **DM/0.15** | 1.59 | 2.31 | 2.29 | 3.33 | 2.88 | 4.19 |
| **DM/0.20** | 1.62 | 2.35 | 2.31 | 3.36 | 3.03 | 4.40 |
| **DM/0.30** | 1.11 | 1.61 | 1.75 | 2.54 | 2.27 | 3.30 |
| **DM/0.40** | 1.10 | 1.60 | 1.66 | 2.41 | 2.20 | 3.20 |

Note: DM/0.00=Sample with 0 % PE; DM/0.05=Sample with 5 % PE; DM/0.0=Sample with 10 % PE; DM/0.15= Sample with 15 % PE; DM/0.20=Sample with 20 % PE; DM/0.30=Sample with 30 % PE. DM/0.40=Sample with 40 % PE

Table 6: Major Properties of Low Density Polyethylene

| **Properties of low density polyethylene** | |
|---|---|
| Density | 0.92 g/cm$^3$ (57 lb/ft$^3$) |
| Young modulus | 0.3 GPa (0.04 x 10$^6$ psi) |
| Degree of crystallinity | 50% |
| Hardness | SD55 |
| Melt Temperature | 120 ℃ |
| Tensile strength(UTS) | 7 MPa (1.0 x 10$^3$ psi) |
| Shear Modulus | 0.21 GPa (0.03 10$^6$ psi) |
| Specific Heat Capacity | 2300 J/kg-K |
| Thermal Conductivity | 0.36 W/m-K |
| Shear Modulus | 0.21 GPa (0.03 10$^6$ psi) |

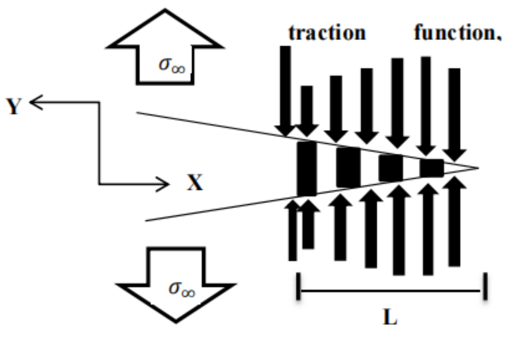
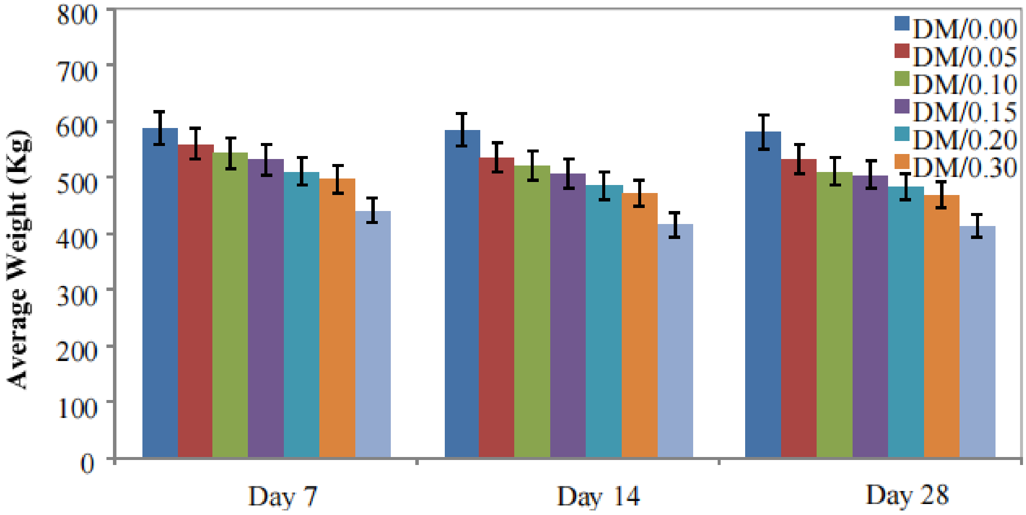



Figure 1: Schematic representation of a large-scale bridging model (Adapted from Azeko et al., 2015)




Number of Days (Days)

Figure 2: Graph Showing Change in Weight of Samples Note: DM/0.00=Sample with 0 % PE; DM/0.05=Sample with 5 % PE; DM/0.0=Sample with 10 % PE; DM/0.15= Sample with 15 % PE; DM/0.20=Sample with 20 %PE; DM/0.30=Sample with 30 % PE. DM/0.40=Sample with 40 % PE

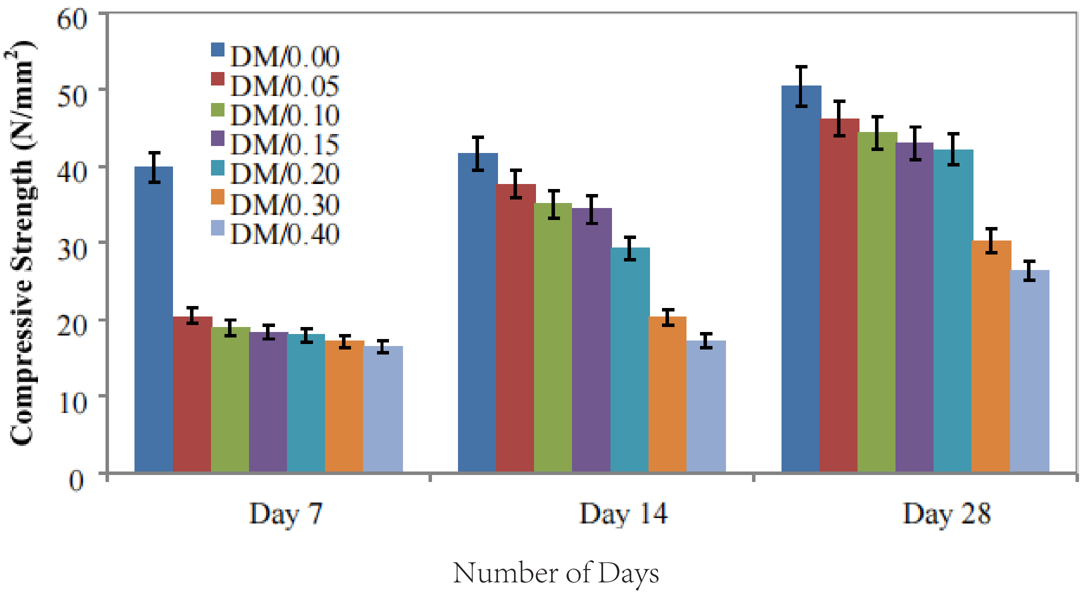



Figure 3: Trend in Compressive Strengths for Different Composite Composition Note: DM/0.00=Sample with 0 % PE; DM/0.05=Sample with 5 % PE; DM/0.0=Sample with 10 % PE; DM/0.15= Sample with 15 % PE; DM/0.20=Sample with 20 % PE; DM/0.30=Sample with 30 % PE. DM/0.40=Sample with 40 % PE

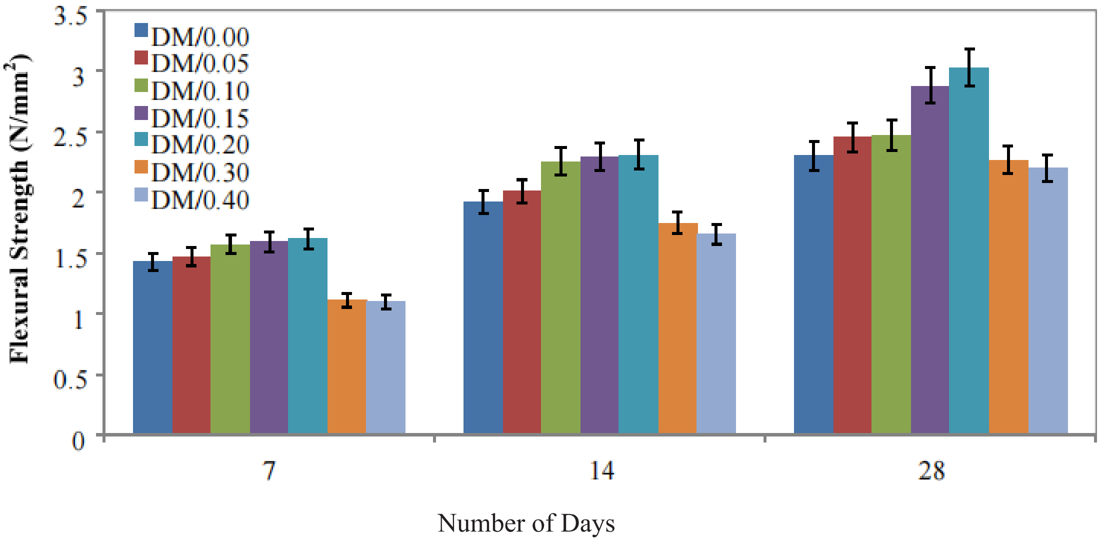



Figure 4: Flexural Strength of Composite Note: DM/0.00=Sample with 0 % PE; DM/0.05=Sample with 5 % PE; DM/0.0=Sample with 10 % PE; DM/0.15= Sample with 15 % PE; DM/0.20=Sample with 20 % PE; DM/0.30=Sample with 30 % PE. DM/0.40=Sample with 40 % PE

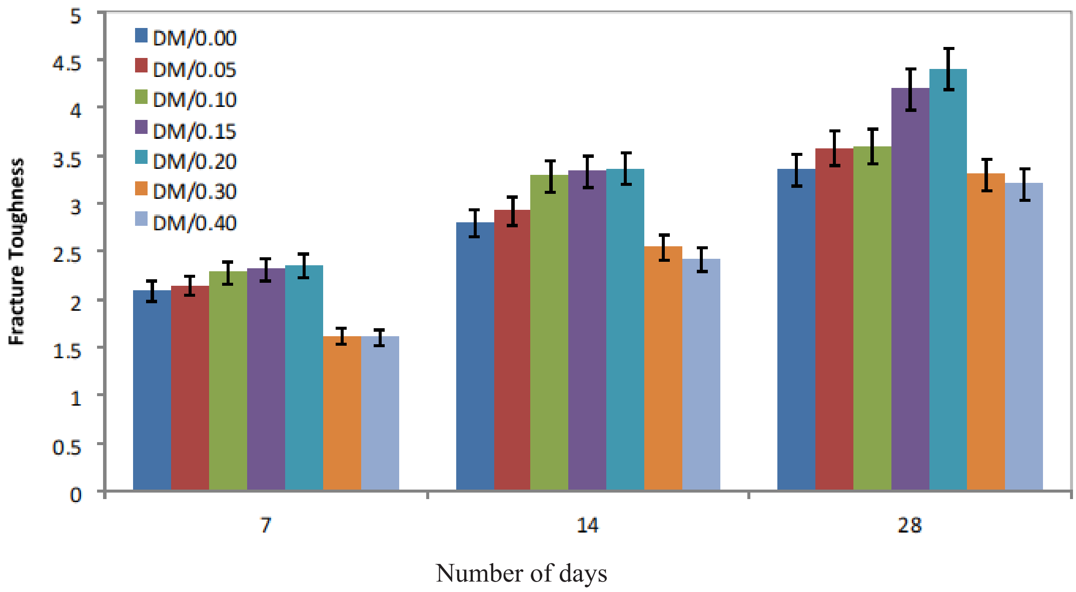



Figure 5: Trend of Fracture Toughness Note: DM/0.00=Sample with 0 % PE; DM/0.05=Sample with 5 % PE; DM/0.0=Sample with 10 % PE; DM/0.15= Sample with 15 % PE; DM/0.20=Sample with 20 % PE; DM/0.30=Sample with 30 % PE. DM/0.40=Sample with 40 % PE

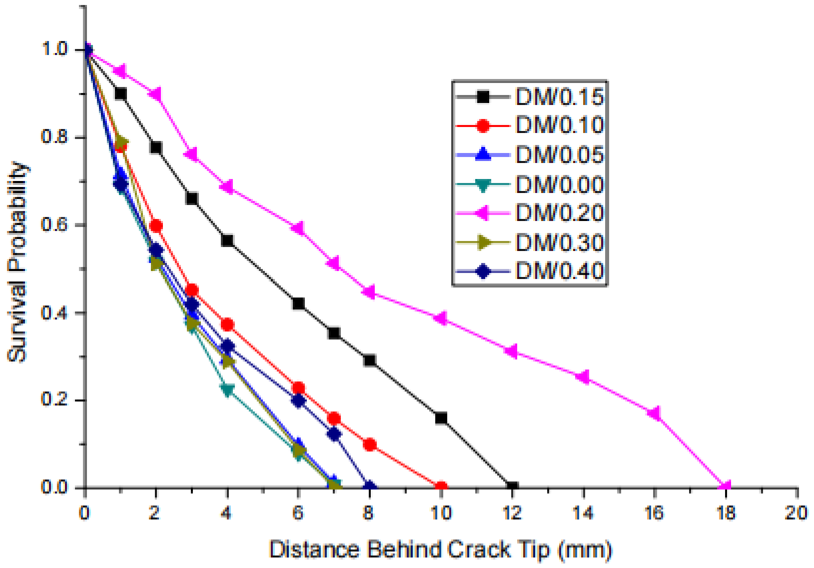



Figure 6: Survival Probability of Cement Mortar at Different Volume Percentages of PE

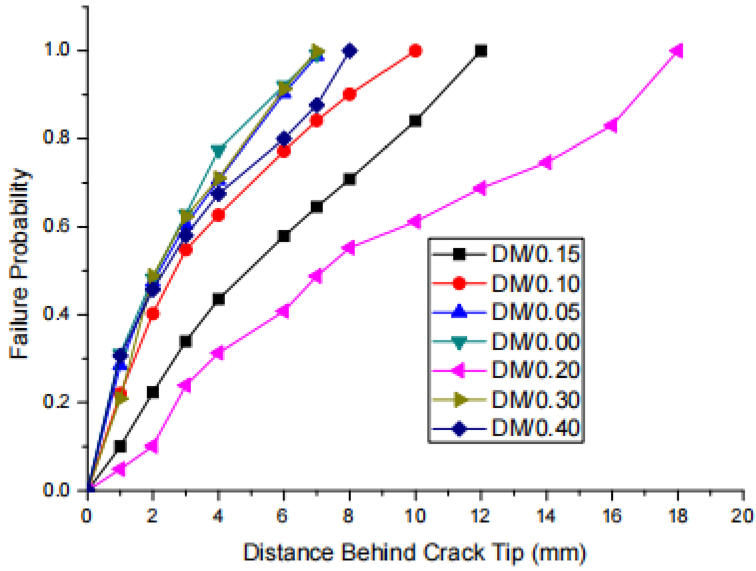



Figure 7: Failure Probability of Cement Mortar at Different Volume Percentages of PE

Note: DM/0.00=Sample with 0 % PE; DM/0.05=Sample with 5 % PE; DM/0.0=Sample with 10 % PE; DM/0.15= Sample with 15 % PE; DM/0.20=Sample with 20 % PE; DM/0.30=Sample with 30 % PE. DM/0.40=Sample with 40 % PE