Flexural Behavior of Reinforced Concrete Beams Containing Polyvinyl Waste Powder (PWP) as Replacement of Cement.

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ABSTRACT

The flexural performance of reinforced concrete beam specimens with polyvinyl waste powder (PWP) as partial replacement of cement is reported in this paper. Cement was replaced with PWP up to 50% by weight at intervals of 10%. The flexural parameters investigated were: the failure patterns, load-deflection characteristics, stiffness, and ultimate moments. The reinforced beam specimens used were 150 x 150 x 1000 mm, and tests were done at the curing age of 28 days. The results showed that: (i) the failure pattern is a combination of flexure and diagonal tension shear failure, (ii) the deflection characteristics of beam specimens improved progressively as the level of cement replacement with polyvinyl waste increased, (iii) reduction in the stiffness of the beam specimens as the percent cement replacement with polyvinyl wastes increased, and (iv) ultimate moments of beam specimens increased with percent replacement of cement with polyvinyl waste up to 20% level.

(Keywords: compressive strength, deflection, polyvinyl waste, stiffness, ultimate moments)

INTRODUCTION

Concrete has continued to maintain its dominant position over all other construction materials due to the fact that it allows innovations, and variety of forms and strengths, using the same basic components of cement, sand, gravel, and water. Of all of these materials, cement is not only the most expensive, but also its production has a negative impact on the environmental due to huge consumption of non-renewable materials. This has created a need to find suitable alternatives as partial replacement of cement.

In recent times, researchers (Hussain and Abdullah, 2009, Givi et al., 2010, Yilmak, 2010, Nassar and Soroushian, 2012, Sooraj, 2013, etc.) have found that some wastes – industrial, agricultural, construction and demolition, etc., could be used as partial replacement of cement to produce concrete of adequate strength, with little or minimal treatment. Some of these materials that have been found suitable either as supplementary cementing materials (SCM) or pozzolans in the production of concrete includes: fly ash, silica fume, rice husk ash, granulated blast furnace slag, recycled glass, construction and demolition waste, etc.

Significant efforts have been expended by researchers on these materials to investigate their structural performance with emphasis on compressive strengths, splitting tensile strength, and modulus of rupture (Domke, 2012; Udoeyo et al., 2012; Nassar and Soroushian, 2012; Vinodsinh and Pitroda, 2013; Sooraj, 2013, etc.).

The present study concerns itself with the potential usage of polyvinyl waste powder (PWP), as partial placement of cement in the production of concrete, with emphasis on its flexural behavior. Polyvinyl wastes are generated in polyvinyl compound environment where materials like roofing sheets, windows, vinyl siding, consumer products, disposable packaging and many every day products are manufactured (CHEJ, 2004). In his investigations, Thornton, (2002) reported an annual global generation of polyvinyl waste powder (PWP) of about 12 million tones, and further stated that they are difficult to dispose and recycle, thus creating environmental problems. The aim of this work, which is a part of a larger program to assess the suitability of polyvinyl waste powder (PWP) as partial replacement of cement in the production of concrete, looks at the flexural response of reinforced concrete beams containing polyvinyl waste up to 50% cement replacement.

With the exception of the works done by Falade et al. (2014) on pulverized bone, and Sangeetha and Joanna (2014) on granulated ground blast furnace slag (GGBS), most researchers have not considered it worthy to investigate the flexural characteristics of concrete containing wastes as partial replacement of cement within the context of reinforced beams, The flexural issues investigated in this study using reinforced concrete beams having polyvinyl waste as partial replacement are: failure pattern, load-deflection characteristics, stiffness, and ultimate moments.

MATERIALS AND PREPARATIONS

In order to carry out the investigations, the following materials namely: cement, fine aggregates, coarse aggregates, water, and polyvinyl waste (PWP) as partial replacement of cement by weight were used.

Ordinary Portland Cement: The cement was produced in accordance with NIS 444 (2003) and BS 12 (1996)

***Fine Aggregates*:** River sand was used for the fine aggregates. They were obtained from Ogun River located at Ibafo, Ogun State. The particle sizes of sand were those passing through sieve with aperture size of 3.35 mm but retained on sieves of 63µm. It was treated to ensure that the sand free from salt and deleterious substances.

***Coarse Aggregates*:** The coarse aggregates, with particle size range between 2.36mm and 20mm were used in this research study as granite chippings.

Polyvinyl Waste Powder (PWP): The material was obtained from a polyvinyl-based roofing sheet manufacturing company based in Ikeja, Nigeria. It was milled to fine powder, with more than 80% passed through 1.18mm sieve, and was bagged and store in a cool place.

***Water*:** Portable water which, that is colorless and odorless, and free of organic matter was used in these experiments.

For the purpose of this investigation, a mix ratio of 1:2:4 by weight of cement, sand and gravel was used, and the water cement ratio of 0.65 was adopted (and which became water/binder ratio in the mix containing polyvinyl waste powder). The cement in the mix was partially replaced with PWP by weight at interval of 10% up to 50%. The concrete with 0% PWP replacement served as the control.

Steel Reinforcement: For the reinforcement of the beam 10 mm diameter bar was used as stirrups and 12 mm diameter bar was used as main bar

EXPERIMENTAL INVESTIGATIONS

Density and Compressive Strength Test

Density and Compressive strength tests were conducted on 150x150x150 cube specimens, at 28-day curing age in accordance with BS 12350 – 6 (2000) and BS 12390 - 3 (2009). A total of 15 numbers of 150 x 150 x 150 cube specimens were prepared using the water/cement ratio of 0.65. Curing of the cubes specimens were by immersion in water right from the moment they were removed from the molds – 24 hours after casting - until the day for their testing when they were removed from the curing water tank and sun-dried before being tested for strength.

The cement replacement with Polyvinyl waste (PW) was up to 50% at interval of 10%. The weight of each cube was taken prior to compressive strength test, and was used to calculate the density. Cube specimens without polyvinyl waste powder served as the control. At the curing age, three specimens were tested for each of the replacement level, and the average was recorded.

Flexural Strength

In order to assess the flexural behavior of concrete containing polyvinyl waste powder as partial replacement of cement, reinforced concrete beams were designed in accordance with BS 8110 (1997), the current code of practice in use in Nigeria. Details of the beam are shown in Figure 1. All linear dimensions are in millimeters, and loadings are in kilonewtons.

All the beams were 150 mm x 150 mm 1000 mm. The beams were reinforced with minimum reinforcement (0.13%bh). The reinforcement for the beams consisted of hot-rolled, deformed

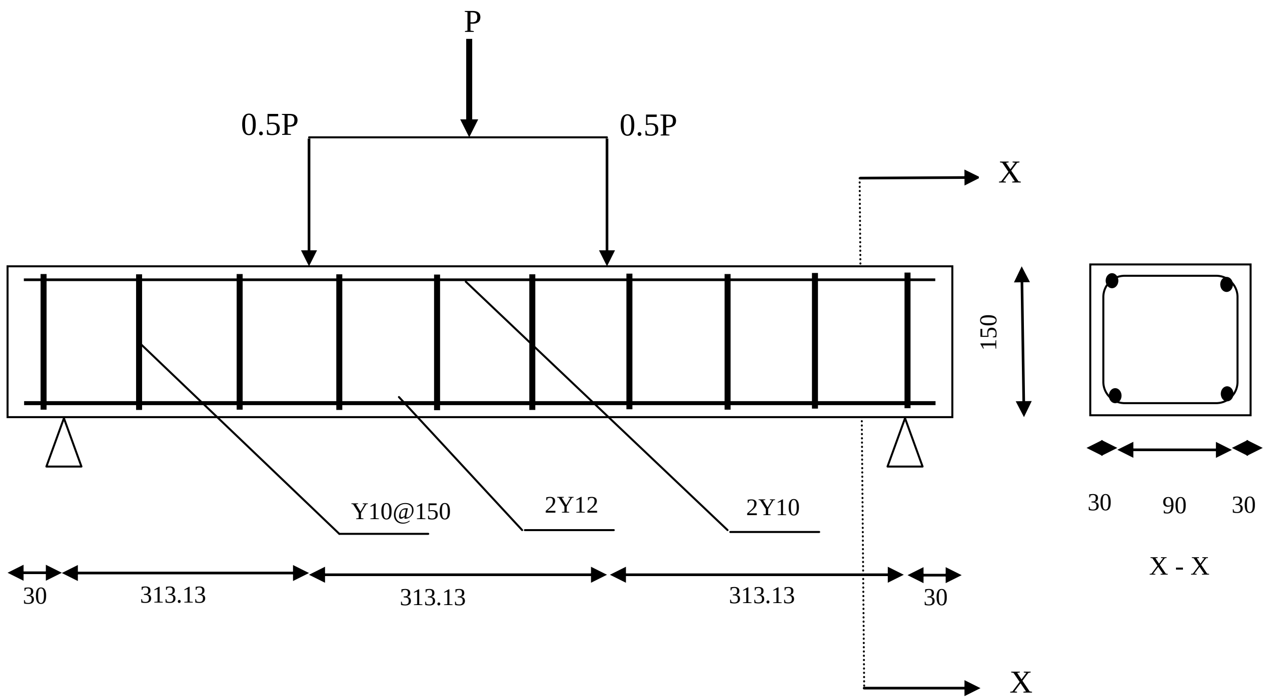

Figure 1: Details of Reinforced Concrete Beam Specimens and Loading Arrangement.

2Y12 mm diameter bars with yield and ultimate stresses of 486.10 N/mm^2 and 728.81 N/mm^2 respectively. For the shear reinforcement, 10mm diameter hot-rolled, deformed bars with yield and ultimate stresses of 475.42 N/mm^2 and 666.90 N/mm^2 respectively were used. The cover was 30mm while the spacing for the shear reinforcement was 150 mm. The replacement of cement with pulverized bone in the beams was varied from 0 to 50% at interval of 10%. Beam specimens without polyvinyl waste powder served as the control.

The beam specimens were produced and tested in accordance with the provisions of BS EN 12390 – 5 (2009). The beam specimens were tested under the third point loading (Figure 2).

Dial gauge was placed under the beam at the mid-span to measure the deflection at regular interval of loading. The Load and the deflection at the development of visible cracks were noted. The beam specimens were tested to failure. The test was terminated when a little increase in load led to very large deflection. A total number of 18 beams were cast and tested for flexural behavior at the curing age 28 days. Three specimens were tested at each curing date and for each of the replacement level, and the average was recorded.

Figure 2: Testing Arrangement of Beam Specimens.

Table 1: Physical Properties of the Materials Used.

Physical Properties	Sand	Coarse Aggregates	Cement	Polyvinyl Waste
Fineness (passing through 600μm)	-	-	99.5	75
Dry Density (kg/m^3)	1405.1	1403.29	-	698.44
Bulk Density (kg/m^3)	1409.55	1407.36	1297.79	839.25
Specific Gravity	2.63	2.66	3.15	2.47
Moisture Content (%)	0.323	0.29	-	20.16
Coefficient of Uniformity (C_u)	1.42	1.50	-	-
Coefficient of Curvature (C_c)	1.41	1.50	-	-

RESULTS AND DISCUSSIONS

Physical Properties

In order to carry out the investigation, the physical properties of materials used were determined and are presented in Table 1. It can be seen from the Table that the PWP has a lower bulk density and specific gravity than the cement. This means that for a given unit weight, more volume of polyvinyl waste will be required in comparison to concrete. Also the fineness of the PWP was lower than that of the cement. However, the moisture content of PWP was however found to be higher than that of cement.

What this suggest is possible increase in water/binder ratio of the mix, which will likely result in lower compressive strength development. Also from the results of the of sieve analysis conducted for the sand and coarse aggregates, the computed coefficient of uniformity ($C_u = \frac{D_{60}}{D_{10}}$) and coefficient of curvature ($C_c = \frac{D_{30} \; x \; D_{30}}{D_{60} \, D_{10}}$) of the sand were respectively 1.45 and 1.42; and for the coarse aggregates were respectively 1.56 and 1.50. Also the fineness modulus was 1.01. These values are within the range for the production of good quality concrete (Mindess et al., 2003).

Effect of Polyvinyl Waste on the Density and the Compressive Strength of Specimens

The effect of polyvinyl waste powder on the 28-day density and strength characteristics are presented in Table 2.

From the table, it can be observed that the density increased with increase in the percent of polyvinyl waste powder (PWP) in the mix. This can be explained by the fact the PWP is finer than the cement (Table 1).

Table 2: 28-Day Density and Compressive Strength Development.

% PWP	Density (Kg/mm^2)	Compressive Strength (N/mm^2)
0	2.48	17.88
10	2.49	18.02
20	2.40	19.11
30	2.51	17.26
40	2.53	16.08
50	2.54	12.44

The possible effect of this is pore refinement of the paste which resulted in more closely-packed paste particles with the attendant densification of the matrix. In addition to this, increased hydration that accompanied curing ages produces products whose overall effect is a denser structure. Also the compressive strength increased up to 20% cement replacement with polyvinyl waste, and afterward decreased. This is suggestive of increased strength-forming hydration activity per unit weight of the polyvinyl waste in comparison with cement up to 20% replacement.

Increase compressive strength up to 20% cement replacement with PWP in relation to the control may not be unconnected with the fineness of the PWP. Although the compressive strength reduced after 20% cement replacement with PWP, this is likely due to the fineness factor in strength determination no longer has influence beyond 20% cement replacement with PWP. However, from the pozzolanic considerations, by the fact of strength activity index (SAI) being 96.53%, and 89.93% respectively for 30% and 40% cement replacement with PWP, still qualify them to be pozzolanic at those replacement levels as per ASTM C 618-08.

Flexural Strength

The major flexural issues addressed in this investigation are: failure pattern, failure load, load-deflection characteristics, bending moments, and stiffness.

Failure Pattern

Two failure patterns were observed for the reinforced beam specimens and were summarized in Table 3. All the specimens having up to 30% cement replacement with polyvinyl waste powder displayed flexural failure. In these specimens, cracks were seen to generate at the mid span, and propagate rapidly, and in some samples, the cracks were severe and accompanied by spalling of concrete at the tension zone.

Table 3: Summary of the Failure Pattern.

Mix Ratio	Failure Pattern
0%	Flexural failure
10%	Flexural failure
20%	Flexural failure
30%	Flexural failure
40%	Flexural and Diagonal Tension Shear failure
50%	Flexural and Diagonal Tension Shear failure

However, for mixes with 40% and 50% cement replacement with polyvinyl waste powder, not only were flexural cracks observed, but also in addition, inclined cracks developed starting at the edge of the support into the direction of load application point. Arya (2004) described this type of failure as diagonal tension shear failure.

Effect of Polyvinyl Waste on Failure Loads of Beam Specimens

The failure loads of the reinforced beam specimens at all the replacement levels are presented in Table 4.

From the table, it can be observed that the failure loads at 28th day curing decreased as the level of cement replacement with polyvinyl waste powder (PWP) increased. This suggests that the inclusion of PWP reduced the resistance to bending of the beam specimens. From 7.48KN at 0% cement replacement to 3.20KN at 50% cement replacement, this is about 49% reduction.

Effect of Polyvinyl Waste on Deflection Characteristics of Beam Specimens

The load-deflection characteristics of beam specimens with PWP as partial replacement of cement are shown in Figure 3. It can be seen the deflection increased as the load increased for all the cement replacement with polyvinyl waste powder (PWP).

Before failure, the beam specimens behave fairly in a linear manner for all the cement replacement with PWP. The results, considering Table 4 and Figure 3 seem to suggest that the inclusion of PWP resulted in reduced deflection.

Table 4: The Failure Loads of the Reinforced Beam Specimens.

Load (KN)	28-day Deflection (mm)					
	0%	10%	20%	30%	40%	50%
0	0	0	0	0	0	0
5	0.32	0.28	0.22	0.20	0.18	0.16
10	1.02	0.84	0.66	0.60	0.54	0.48
15	1.70	1.40	1.10	1.00	0.90	0.80
20	2.38	1.96	1.54	1.40	1.26	1.12
25	3.06	2.52	1.98	1.80	1.62	1.44
30	3.74	3.08	2.42	2.20	1.98	1.76
35	4.52	3.74	2.96	2.70	2.44	2.18
40	5.10	4.20	3.70	3.00	2.70	2.40
45	5.88	4.86	3.84	3.50	3.16	2.82
50	6.12	5.04	4.06	3.60	3.24	2.88
55	6.46	5.32	4.28	3.80	3.42	3.04
60	6.80	5.90	4.49	4.00	3.60	3.20
65	7.06	5.88	4.72	4.20	-	-
70	7.28	6.16	5.00	-	-	-
75	7.48	6.24	-	-	-	-

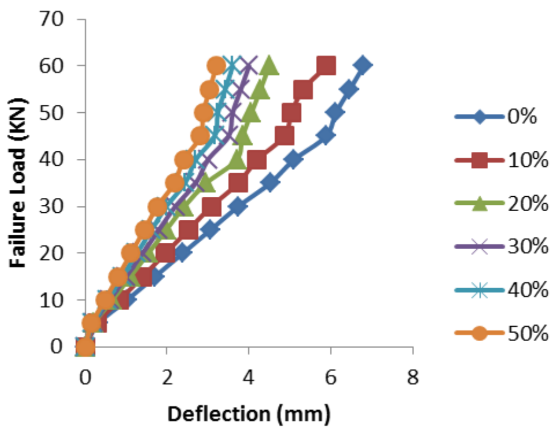

Figure 3: Deflection Characteristics of Specimens with PWP as Replacement of Cement.

For example, at the 60KN load, the observed deflections were 6.8, 5.9, 4.49, 4.0, 3.60, and 3.20 respectively for 0%, 10%, 20%, 30%, 40%, and 50% cement replacement with polyvinyl waste powder. From the result of the final deflection presented in Table 5, it is obvious that inclusion of PWP resulted in significant reduction in deflection in relation to the control. In order words, samples containing PWP have better defection characteristics than samples without PWP.

Table 5: Effect of Polyvinyl Waste Powder on Deflection of Concrete Beam.

% PWP	Deflection at first Cracks (mm)	Deflection at Failure (mm)	% Difference from the Control
0	6.20	7.48	-
10	5.21	6.24	16.58
20	3.98	5.00	33.16
30	3.63	4.20	43.85
40	3.28	3.60	51.87
50	2.98	3.20	57.22

However, it is to be noted that the code BS 8110 (1997) limits the serviceability limit state of deflection (in this case, at first crack)to within $\frac{l}{250}$, which in this case is 4mm (i.e. $\frac{1000}{250}$). The beam specimens with 0% and 10% cement replacement with PWP did not meet this requirement

Effect of Polyvinyl Waste on the Stiffness of the Specimens

According to Sin (2007), the gradient of the load-deflection curve is an indication of beam stiffness. The computed stiffness from the load-deflection curve is presented in Table 6.

Table 6: Effect of PWP on Stiffness of Beam Specimens.

% PWP	Stiffness (KN/mm)	Variation from the Control (%)
0	10.03	-
10	12.02	19.84
20	14.00	39.58
30	15.48	54.34
40	16.67	66.20
50	18.75	86.94

In relation to the control, gradual reduction in the beam stiffness resulted as the level of cement replacement with polyvinyl waste increased.

Effect of Polyvinyl Waste on the Bending Moments of Beam Specimens

The theoretical moment was calculated for each of the beam specimens from the equation derived by assuming the idealization of rectangular stress block using average stress of 0.67fcu over 0.9 times the neutral axis depth, that is, the stress block contained in the BS 8110 (1997). The equation is:

$$M_u = 0.156 f_{cu} b d^2 \qquad \textbf{(1)}$$

where:

f_{cu} = compressive strength of the specimens for each cement replacement level with polyvinyl waste (N/mm^2).

b = width of the beam specimens (mm)

d = effective depth (mm)

The experimental moment (M_{EXP}) was calculated by using the equation for the structural form that is compatible with the third point loading configuration as shown in Figure 4.

The bending moment equation is:

$$M = 0.167Pl \quad \textbf{(2)}$$

where:

M = the maximum bending moment (KN.m)

P = the failure load (KN)

l = the span of the beam specimen (m)

The failure load, theoretical ultimate moment (M_{BS}) and the experimental ultimate moments (M_{EXP}) computed from Equations 1 and 2 are shown in Table 7.

It is to be noted however that in computing the M_{EXP}, the service load was obtained by the dividing the load at the occurrence of visible cracks by 1.6. This presupposes that flexural failure has already occurred at the load, and this load was thus used to calculate the experimental ultimate moments

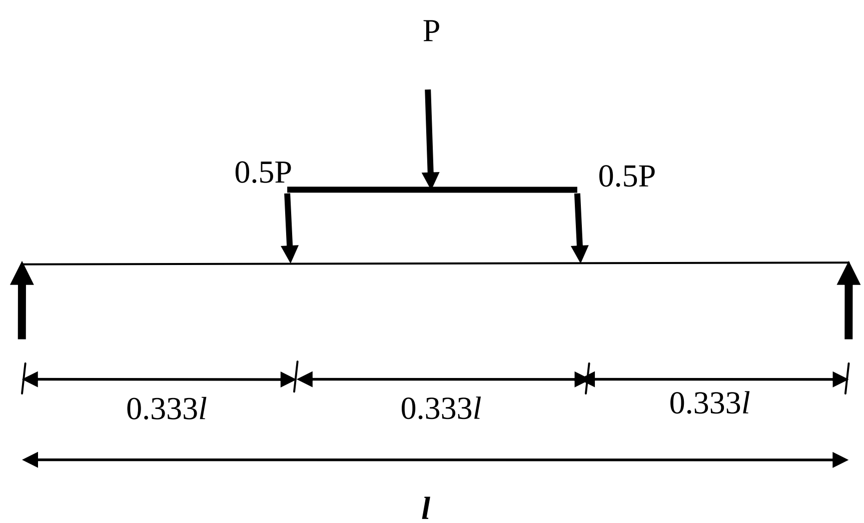

Figure 4: Structural Configuration for Third Point Loading.

Table 7: Comparison between Experimental and Theoretical Bending Moments.

% PWP	Cracking Load (KN)	Compressive Strength (N/mm^2)	Moments (KN.m)		$\frac{M_E}{M_T}$
			Experimental (M_E)	Theoretical (M_T)	
0	37.50	17.88	6.26	5.44	1.15
10	37.20	18.02	6.51	5.48	1.13
20	36.46	19.11	6.79	5.81	1.12
30	33.86	17.26	5.66	5.25	1.08
40	31.25	16.08	5.22	4.89	1.07
50	31.00	12.44	5.18	3.78	1.37

The effects of polyvinyl waste powder on the bending moments (experimental and theoretical) can be seen in Table 7. The bending moments (both the theoretical and experimental) reduced with increasing PWP content up to 20% replacement levels. The moments were calculated on the assumption that failure has taken place at the onset of the first visible crack. The values of the experimental Moment are consistently higher than those of theoretical moments by the idealized rectangular stress block as used in BS 8110 (1997). But the difference is however to be expected in view of possible errors in arising from variations in materials properties.

From the above results, it obvious that the optimum percent of cement replacement with polyvinyl waste occurred at 20% replacement. At 20% cement replacement value, both the compressive strength and the bending moments were highest.

CONCLUSIONS

1) The specimens' mode of failure were flexural up to 30% cement replacement with polyvinyl waste. At all other replacement levels, combination of flexural and diagonal tension shear failures were noticed.

2) The deflection characteristics of beam specimens improved progressively as the level of cement replacement with polyvinyl waste increased.

3) There was reduction in the stiffness of the beam specimens as the percent cement replacement with polyvinyl wastes increased.

4) Ultimate moments of beam specimens increased with percent replacement of cement with polyvinyl waste up to 20% level.

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