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Effects of Water/Binder Ratio on the Structural Properties of Concrete Containing Polyvinyl Waste Powder (PWP)

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ABSTRACT: Structural use of wastes will serve as innovative way of converting wastes to wealth and as efficient mean of waste removal, leading to a cleaner and sustainable environment. This paper presents the results of investigation conducted to determine the effect of water/cement ratio on structural properties of concrete containing polyvinyl waste powder (PWP) as partial replacement of cement. Cement was replaced with PWP up to 40% by weight at interval of 10% for the concrete used for this investigation. The parameters investigated using the water/binder ratio of 0.55, 0.60, 0.65, and 0.70 were: workability, density, compressive strength, and the tensile strength. The result shows that: (i) slump of the specimens increased with the water/binder ratio, (ii) the compressive strengths increased with decreased in water/binder ratio at all the replacement level of cement with PWP, (iii) specimens with 0.55, 0.60, and 0.65 water/binder ratios developed higher compressive strengths when compared to the control specimens up to 20% cement replacement values, (vi) specimens with 0.55, 0.60, and 0.65 water/binder ratios developed higher splitting tensile strength compared to the control sample up to 30% cement replacement polyvinyl waste powder (PWP). It can be concluded that concrete containing PWP up to 20% as a replacement of cement, will develop adequate compressive strength that is acceptable for quality control. However, durability implications of the use of PWP in concrete production should be investigated.

Keywords: Compressive Strength; Polyvinyl waste powder; Splitting Strength; Workability.

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INTRODUCTION

The production of structural concrete by replacing the cement component partially with suitable wastes is bound to result in great savings and a cleaner environment. This is more so in developing countries where wastes generation is growing at rate that far exceeds their capacity to develop efficient waste disposal system that is typical of advanced countries (Thornton, 2002 and Falade et al., 2013a). In Nigeria for example, wastes from industrial, agricultural, and construction activities are generated daily. Absence of proper waste disposal system, resulting in indiscriminate dumping, burning, etc. is raising serious environmental issues. However, recent research efforts have seen some of these wastes being found to be suitable for the production of concrete, thus serving as an innovative means of getting rid of potentially dangerous materials (Fapohunda et al., 2014). The use of fly ash as partial replacement of cement in concrete production was investigated by (Alaam et al., 2006). They found that up to 10% cement replacement with fly ash by weight, there was no reduction in compressive strength. However, Memon et al. (2010) recommended a replacement level of up to 25% by weight. The works of Ephraim et al., (2012) on the use of rice husk ash

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up to 25% as partial replacement of cement by weight in concrete production revealed an enhanced compressive strength but with increased water demand. Oyekan and Kamiyo (2008) also did investigations on the use of rice husk ash as partial replacement of cement in concrete. They observed an increased in the compressive strength of 17% at 5% cement replacement by weight with rice husk ash. Similar results on suitability of rice husk ash as partial replacement of cement were obtained by (Opeyemi and Makinde (2012). Other wastes materials that have been found suitable as partial replacement of cement include: palm fuel ash (Abdullah et al., 2006; Hussin and Abdullah, 2009; and Abdul and Abubakir, 2011), pulverized bone (Falade et al., 2012, Falade et al., 2013b, and Falade et al., 2014), cassava peel ash (Salau and Olonode, 2011; Salau et al., 2012), etc. All these wastes, though not cementitious in themselves, but were able to attain to cementitious material in finely grounded state and in the presence of water and $Ca(OH)_2$ released in the cause of hydration of cement. They were thus classified as pozzolanic materials, or supplementing cementing materials. One waste that is yet to be investigated for its possible pozzolanic status, or characterised as supplementary cementing material, is polyvinyl waste powder (PWP); and thus the focus of this paper. Polyvinyl waste powder is obtained from polyvinyl waste. Polyvinyl are materials made from polymers of vinyl compounds, which are subsequently used to manufacture variety of materials including: (i) building materials (roofing sheets, windows, vinyl siding), (ii) consumer products, (iii) disposable packaging, and (iv) many every day products (Chej, 2014). Annual generation of polyvinyl waste stands at about 12 million tonnes (Thornton, 2002). Difficulties in disposing these wastes are creating environmental problems. Thus the aim of this study is to investigate the possibility of using polyvinyl waste powder (PWP) as partial replacement of cement in the production of concrete, by looking at the effect of water/cement (water/binder) ratio. The parameters investigated at chosen water/cement ratios, in order to achieve this aim includes: workability, density, compressive strength, tensile strength.

MATERIALS AND METHODS

Materials

The main objective of this research is to establish the effect of water cement ratios on the strength properties of concrete containing PWP as partial replacement of cement. The materials used to achieve this objective are: 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 from obtained from Ogun River located at a location called Ibafo in Ogun State, Nigeria. 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 they are from salty and other deleterious substances.

Coarse Aggregates. The coarse aggregates used in this research study were granite chippings with particle size range between 2.36mm and 20mm, obtained from a quarry.

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

Water. Portable water which was fresh, colourless and odourless 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 0.55, 0.60, 0.65, and 0.70 were 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% PW replacement, using the same set of water/cement ratios, served as the control.

Experimental Investigations

Workability Test

The slump test was carried out in accordance with the provisions of BS EN 12350 (2000). The replacement was done at the interval of 10% up to 50% cement replacement with Polyvinyl waste powder (PWP), for each of the water/cement (water/binder) ratio adopted for this work. The sample without PWP serves as the control.

Density and Compressive Strength Test

Density and Compressive strength tests were conducted on 150x150x150 cube in accordance with BS EN 12350 (2000) and BS EN 12390 (2009) for each of the water/cement (water/binder) ratio adopted for this work. A total of 240 numbers of 150 x 150 x 150 cube specimens were prepared. All the cubes specimens were cured by immersion in water right from the moment they were removed from the moulds – 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 compressive strength test was carried out on the cube specimens at curing age of 7, 14, 21, 28 days. The specimens' preparations and testing were in accordance with BS EN 12390 (2009). The cement replacement with polyvinyl waste powder (PWP) to 40% at interval of 10%. The weight of each cube was taken prior to compressive strength test, and was used to calculate the density.

Tensile Strength

The splitting tensile strength was carried out on the concrete specimens in accordance with the provision of BS EN 12390 (2009). The specimens were 150 x 150 x 300 cylinders. Figure 1 shows the testing arrangement. The splitting strengths were determined on 600KN Avery Denison Universal Testing machine at a loading rate of 120KN/min until failure. The splitting tensile strength (Ts) is then calculated using equation 1:

$$T_s = \frac{2P}{\pi l d} \qquad (1)$$

where: Ts = splitting tensile strength (N/mm2), P = maximum applied load (in Newtons) by the testing machine, l = length of the specimen (mm), d = diameter of the specimen (mm)

Figure 1: Splitting Test Specimens

RESULTS AND DISCUSSION

Workability of Concrete Specimens containing PWP

True slumps were recorded for all the specimens at all the water cement ratio considered and at all cement replacement with polyvinyl waste powder (PWP). This is an indication that inclusion of polyvinyl waste powder (PWP) in the mix has no effect on the cohesiveness of the mix to the extent of causing shear or collapse slump. The effect of polyvinyl waste powder on the workability of the concrete, measured in terms of slump loss is shown in Figures 2. From figure 2, it can be observed that by increasing the percent replacement of cement with PWP in the mix, a progressive reduction in the observed values for the slump of the concrete specimens resulted, for all the water/cement (water/binder) ratio.

From the pattern of this behaviour, one can conclude that addition of polyvinyl waste powder had a dehydrating effect on the concrete. The consequence of this behaviour is the loss of water that is meant for the strength-forming cement hydration process, and loss of strength may result. As such more water will be required to make the concrete workable, and for the concrete to attain to the desired strength. The effect of water/cement ratio (water/binder) on the slump characteristics of the concrete containing polyvinyl waste powder, at all the replacement level considered, is shown in Figure 3.

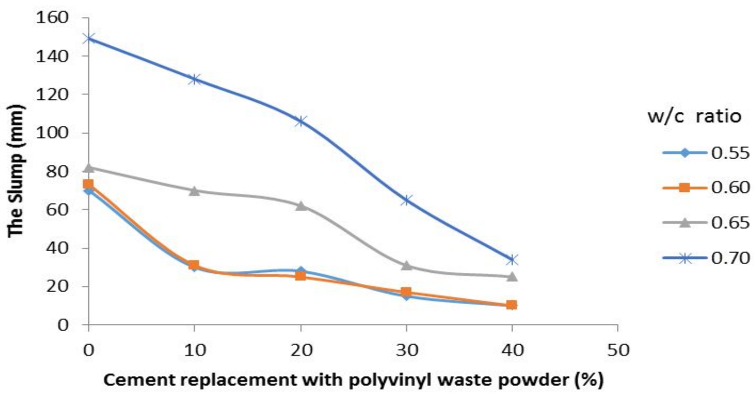

Figure 2: Effect of Polyvinyl Waste Powder on the Slump Characteristics of Concrete

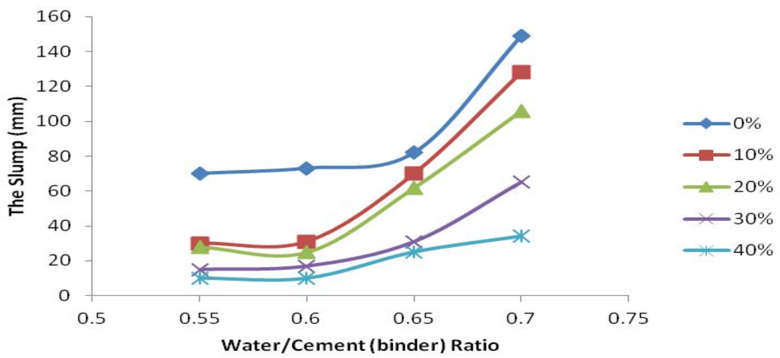

Figure 3: Effect of Water/Cement (binder) Ratio on the Slump Characteristics of Concrete with Polyvinyl Waste Powder (PWP)

At all the cement replacement level, the slump increased with water/binder ratio. That is, the higher the water/cement ratio, the higher the observed slump. For example, for mix containing 20% PWP, the slump increased from 35 to 13mm. Other mixes also showed this pattern. The increased in the slump witnessed can be ascribed to the fact that more water is available in the mix with increasing water content. The availability of more water resulted in a more fluidy and workable concrete. However, it is to be noted that all the specimens display true slump despite increase in the slump values. A collapse slump would have been an indication of the disruption of the cohesiveness of the materials at higher water/cement ratios.

Density of the Concrete Specimens with PWP

Efficient application of concrete begins with knowledge of its density, bearing in mind that three classes of concrete exist on the bases of density which according to Falade et al., 2011) are: heavy weight with density range between 3360 and 3680kg/m^3, normal weight concrete with density range from 2200 to 2550 kg/m^3, and lightweight concrete with density range < 2200 kg/m^3. For all the specimens, the recorded densities for all cement replacement with PWP, and at all the water/binder ratio used, were between 2370 – 2580 kg/m^3. This can be observed from the typical day 28 curing densities presented in Table 1. These values clearly fell in the range of densities for normal weight concrete. These suggest that the use of polyvinyl waste powder as partial replacement of cement up to 40% in concrete production with result in concrete that can be used for conventional purposes, within the water/cement ratios used for this investigation.

Compressive Strength of Concrete Specimens with PWP

The effects of water/binder ratio on strength development are presented in Figures 4 – 8, at

Table 1: Effect of Water/Cement ratio on the Density (kg/m^3) of Concrete Specimens containing PWP

*w/b ratio	0.55	0.60	0.65	0.70
0 % PWP	2540 ± 0.99	2501 ± 1.09	2461 ± 1.02	2471 ± 0.00
10 % PWP	2601 ± 1.20	2580 ± 1.25	2490 ± 1.02	2482 ± 0.00
20 % PWP	2512 ± 1.25	2511 ± 1.25	2461 ± 0.00	2511 ± 1.02
30 % PWP	2562 ± 1.25	2541 ± 1.10	2483 ± 0.00	2490 ± 0.80
40 % PWP	2583 ± 1.00	2482 ± 1.00	2462 ± 1.00	2482 ± 0.00

** water binder ratio*

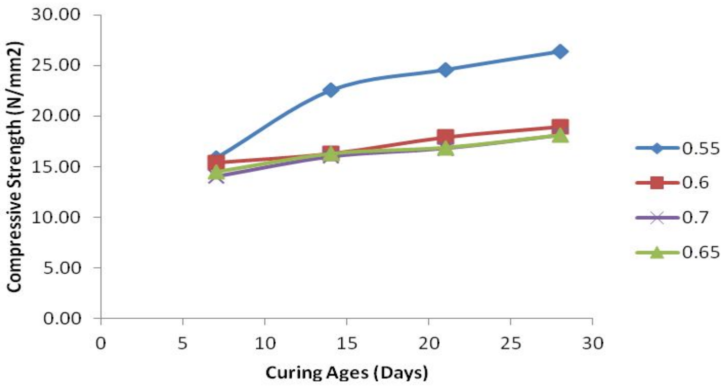

Figure 4: Strength development at all the water/binder ratio for Concrete Specimens with 0% Polyvinyl Waste Powder (PWP)

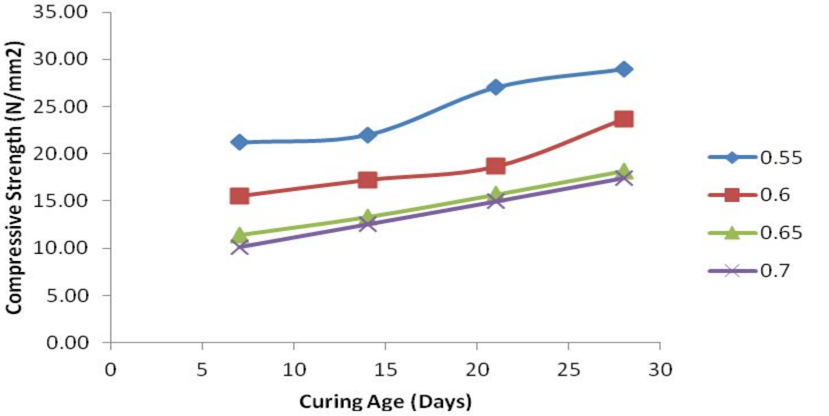

Figure 5: Strength development at all the water/binder ratio for Concrete Specimens with 10% cement Replacement with Polyvinyl Waste Powder (PWP)

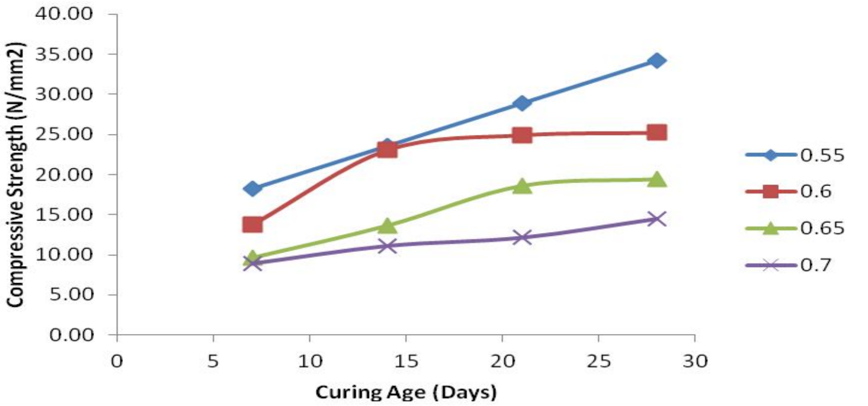

Figure 6: Strength development at all the water/binder ratio for Concrete Specimens with 20% cement Replacement with Polyvinyl Waste Powder (PWP)

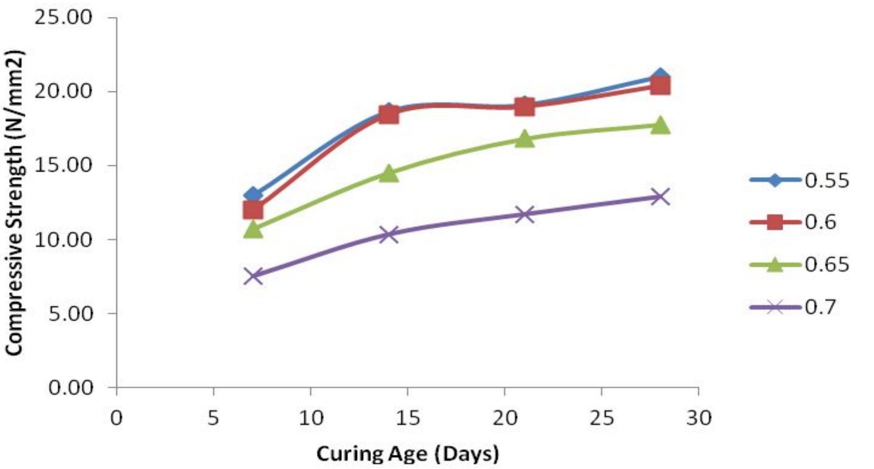

Figure 7: Strength development at all the water/binder ratio for Concrete Specimens with 30% cement Replacement with Polyvinyl Waste Powder (PWP)

all cement replacement with polyvinyl waste. From these figures, it can be observed that the specimens with the lowest water/binder ratio (0.55) developed the highest strengths, followed by the next water/binder ratio. For example, at 10% cement replacement with PWP, the compressive strengths were 28.98, 23.71, 18.2 and 17.48 N/mm^2 respectively at 0.55, 0.60, 0.65 and 0.70 water/cement ratios. This pattern was also followed at the other percentage levels of cement replacement with PWP. This behaviour is in conformity with established pattern in concrete technology, where it is known that higher water/binder ratio is always accompanied by reduction in strength and lower water/binder ratio resulted in higher strength. The reason being that at higher water/binder ratio, more capillary pores are formed leading to more porous matrix. A porous matrix results in reduced density, and a reduced density will be accompanied by a reduced strength (Neville. 2003).

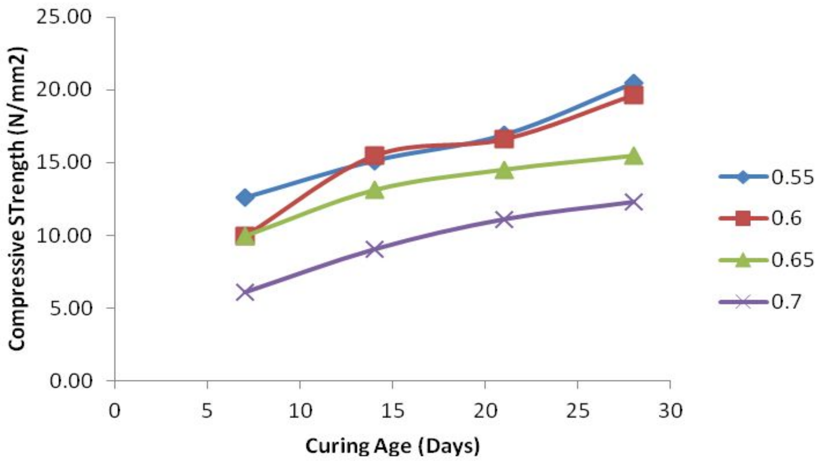

Figure 8: Strength development at all the water/binder ratio for Concrete Specimens with 0% cement Replacement with Polyvinyl Waste Powder (PWP)

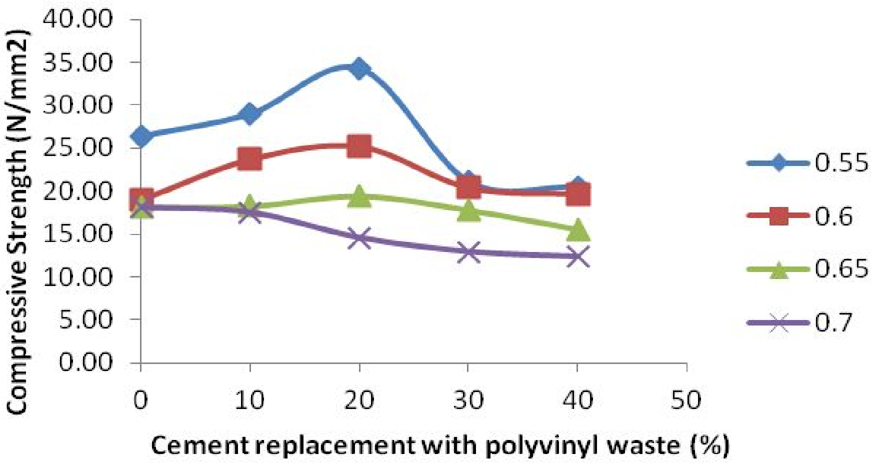

Figure 9: Day 28 Variation of Compressive Strength of Concrete Specimens with PWP as Replacement of Cement

Table 2: Determination of the Pozzolanicity of Polyvinyl waste powder (PWP) through Strength Activity Index (SAI)

w/b ratio	0.55		0.60		0.65		0.70	
Mix	CS	SAI (%)	CS	SAI (%)	CS	SAI (%)	CS	SAI (%)
0 % PWP	26.36 ± 0.13	100.00	18.96 ± 0.23	100.00	18.10 ± 0.20	100.00	18.08 ±0.25	100.00
10 % PWP	28.98 ± 0.21	109.94	23.71 ± 0.34	125.05	18.22 ± 0.20	100.66	17.48 ± 0.20	96.68
20 % PWP	34.24 ± 0.22	129.89	25.19 ± 0.12	132.86	19.41 ± 0.12	107.24	14.52 ± 0.00	80.31
30 % PWP	21.02 ± 0.22	79.72	20.37 ± 0.22	110.07	17.76 ± 0.12	98.12	12.89 ± 0.00	71.29
40 % PWP	20.44 ± 0.12	77.54	19.63 ± 0.22	103.53	15.48 ± 0.12	85.53	12.30 ± 0.25	68.03

w/b ratio = water/binder ratio, CS = compressive strength (N/mm^2)

However, the 28-day strength development for all the water/binder ratio is presented in Figure 9. It can be observed that the 28-day strength of specimens having water/binder ratio of 0.55, 0.60, and 0.65 increased with percent increase in the cement replacement with polyvinyl waste up to 20% after which it started to decrease. The specimens with water/binder ratio of 0.70 developed lower compressive strength relative to the control.

In order to determine the pozzolanicity of PWP, the Strength Activity Index (SAI) was computed for the specimens and presented in Table 2. The strength activity index is measured as the strength developed by the blend of the suspected pozzolan relative to the control. For any material to be classified as a pozzolan, the strength of the blended sample at 7-day and/or 28-day must not be less than the 75% of the strength of control strength (ASTM C 618, 2008). The data presented in Table 2 are for 28-day curing.

From the Table, it can be observed that for water/binder ratio of 0.55, all the specimens have pozzolanic traits at all the replacement level of cement with polyvinyl waste, both at 7- and 28-day curing. At water/binder ratio of 0.60, only the samples containing 40% of PWP as replacement of cement did not have pozzolanic characteristics at 7-day curing. However, all the samples were pozzolanic at 28-day curing for all replacement levels. The samples with water/binder ratio of 0.65 were pozzolanic only up to 10% cement replacement with polyvinyl waste at 7-day curing. All the sample were however pozzolanic at 28-day curing at all the cement replacement levels with polyvinyl waste. None of the samples with 0.70 water/binder ratio was pozzolanic at 7-day curing, and were pozzolanic up to 20% cement replacement with polyvinyl waste powder at 28-day curing. But using the 28-day curing as the standard, it can be seen from the table that at all the replacement levels, the samples with water/binder ratio of 0.55, 0.60, and 0.65 were all pozzolanic, but the pozzolanicity of specimens with water/binder ratio of 070 occurred when the replacement level is not beyond 20%.

Tensile strength of Concrete specimens with PWP

The results of the splitting strength tests to assess the pattern of development at different water/binder ratios are presented in Figures 10 – 14. From Figures, it can be observed that the splitting strength increased with curing age for all the specimens. Also the splitting tensile strength increased with lower water/binder ratio up to 20% cement replacement with polyvinyl waste powder at all curing ages.

However, beyond 20% cement replacement with PWP, the splitting strength still increased with

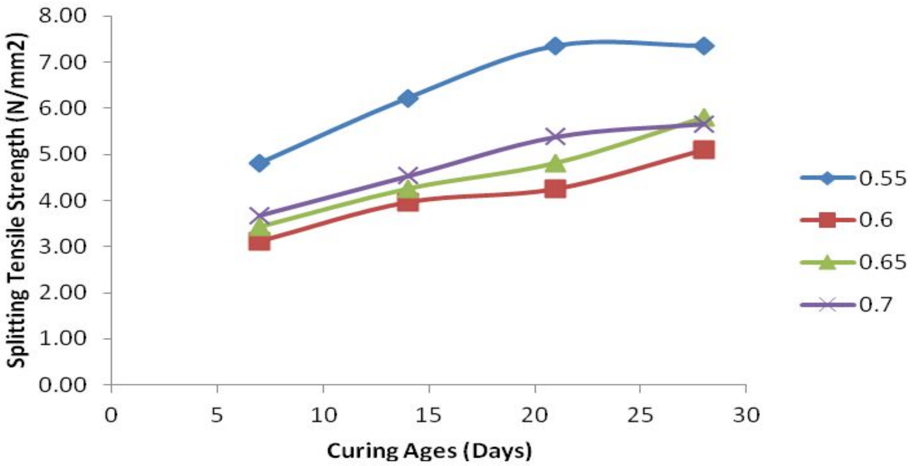

Figure 10: Variation of Splitting Strength with Curing Age at 0% cement replacement with polyvinyl waste powder (PWP)

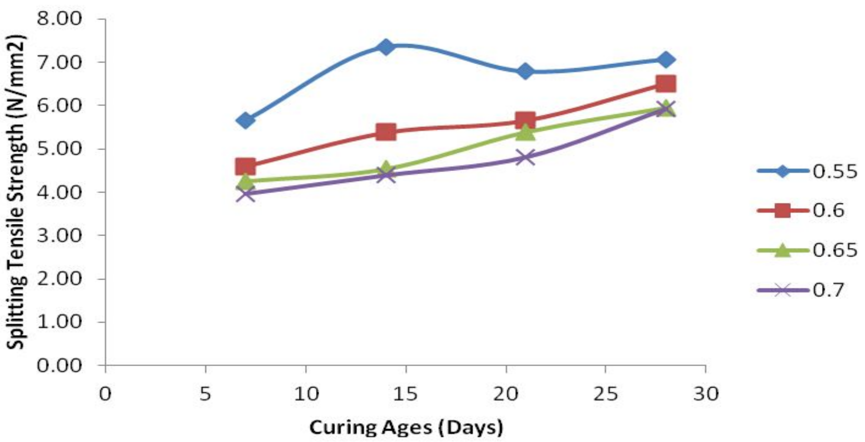

Figure 11: Variation of Splitting Strength with Curing Age at 10% cement replacement with polyvinyl waste powder (PWP)

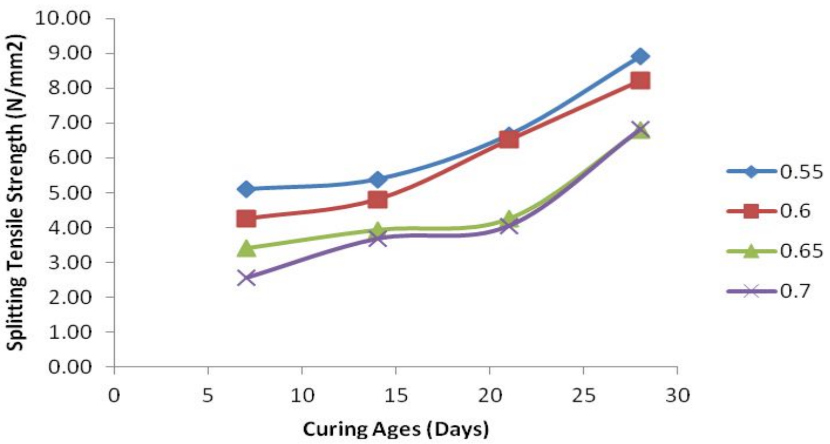

Figure 12: Variation of Splitting Strength with Curing Age at 20% cement replacement with polyvinyl waste powder (PWP)

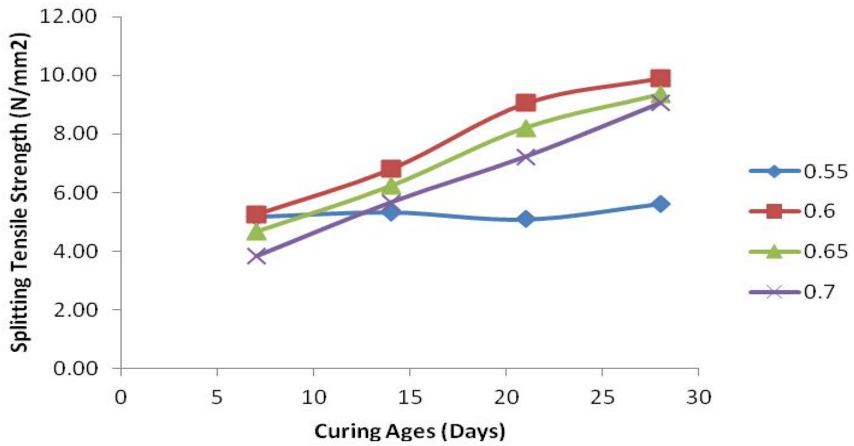

Figure 13: Variation of Splitting Strength with Curing Age at 30% cement replacement with polyvinyl waste powder (PWP)

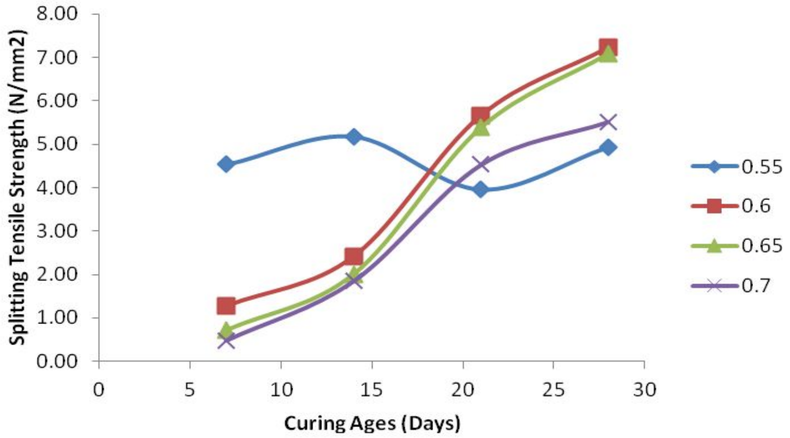

Figure 14: Variation of Splitting Strength with Curing Age at 40% cement replacement with polyvinyl waste powder (PWP)

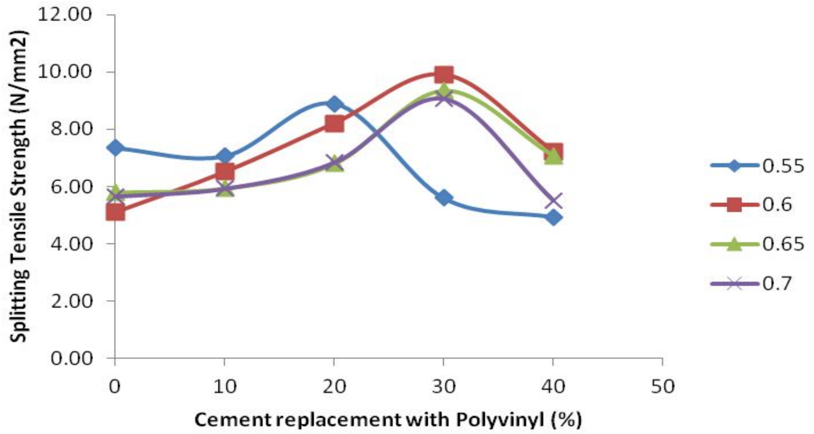

Figure 15: 28-day Splitting Strength development for concrete Specimens containing PWP as partial replacement of Cement, at all the water/binder ratios

curing age for all the water/binder ratio except 0.55 specimens (Figures 13 – 14). The reduced splitting strength observed at the water/binder ratio of 0.55 may be due to the relatively dryness of the specimens which encourage the development and generation of micro-crack in the internal matrix of the specimens, leading to early failure. The 28-day splitting strength is presented in Figure 15.

From the figure, the highest splitting strength for specimens with 0.55 water/binder ratio occurred at 20% cement replacement with polyvinyl waste. However for specimens with water/binder ratio of 0.60, 0.65, and 0.70 the highest splitting strength occurred at 30% cement replacement with polyvinyl waste. The reason for low strength development of 0.55 water/binder ratio specimens may be due to the cumulative effect of the increased dehydrating effect of polyvinyl waste powder as higher replacement levels. This will subsequently make the specimens dryer and thus susceptible to crack, leading to reduced splitting strength.
One significant finding from this work was the effect of water-cement ratio on the strength development of concrete. In concrete works, assuming full compaction, and at a given age and normal temperature, the strength of concrete can be taken to be inversely proportional to the water/cement ratio (Neville and Brooks, 2008). But it is to be noted that at the time this Law, attributed to Abram, was discovered, the materials used for binder in the production of concrete was ordinary Portland cement. Substituting processed wastes as done in this work was not in practice then. What is not known is whether the Law could still hold if the cement fraction of the concrete mix is substituted with any wastes – industrial and agricultural; in this case, polyvinyl waste powder (PWP). The results obtained from this investigation showed the validity of the Law for concrete containing up to 20% PWP as partial replacement of cement.

CONCLUSION

From the results of this investigation, the following conclusions are made.

1) At all the cement replacement level, the slump increased with increase in the water/binder ratio.
2) At all the water/binder ratios investigated, the concrete densities remain with the category for normal weight concrete.
3) At all the cement replacement level with polyvinyl waste powder, the compressive strength increased as the water/binder ratio decreased.
4) Specimens with 0.55, 0.60, and 0.65 up to 20% cement replacement with polyvinyl waste powder developed higher compressive strength compared to the control samples.
5) All the specimens having water/binder ratio of 0.55, 0.60, and 0.65 exhibited pozzolanic behaviour by virtue of satisfactory strength activity index as per ASTM C 618-08.
6) For specimens with 0.55, 0.60, and 0.65 and up to 30% cement replacement with polyvinyl waste, splitting strengths were higher than the control.

Though the results of this investigation showed that concrete containing PWP up to 20% as a replacement of cement, will develop adequate compressive strength that is acceptable for quality control, there are other structural issues that this investigation did not cover, but very relevant to wide acceptance and use of PWP for concrete production. For example, the flexural characteristics and the durability performance of concrete containing PWP need to be studied; and these are therefore recommended for further investigations.

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