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Research Article

Polymer Waste Material as Partial Replacement of Fine Aggregate in Concrete Production

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Abstract: The aim of the study is to assess the quality of concrete produced with polymer waste as partial replacement of fine aggregate with a view to establishing areas where such concrete can be used. It is an experimental research that entails the following steps: First, the polymer waste material, PWM, was collected from dumps and processed; then its melting point determined. A varying proportion of PWM was used as partial replacement of fine aggregate A nominal mix of 1:3:6 was used to prepare 150×150×150 mm concrete cubes specimens with different proportion of 0, 10, 20 and 30%, respectively PWM partial substitution of fine aggregate. Samples were subjected to workability, compressive and tensile strength tests. Results show that PWM content has inverse relationship with the workability, compressive and tensile strengths. For example, an increase of 30% PWM results to about 53 and 73.3% decrease in compressive and tensile strengths, respectively. The compressive strength of the samples is in the range of 22.8-12.3 N/mm^2 while the tensile strength ranges from 1.10-0.56 N/mm^2. It is recommended that the concrete should not be used for structural work but such concrete has high water retention capacity. As such, the possibility of using it as a nuclear radiation shield should be investigated.

Keywords: Compressive strength, concrete, fine aggregates, partial replacement, polymer waste

INTRODUCTION

Literature review: Safe and efficient waste disposal is one of the major activities that improve the standard of environmental condition. However, according to Maigari (1999) In AbdulGaffar (2009) the world is currently generating billions of tonnes of waste annually but disposes very few millions properly with less than six billion tones being re-cycled annually.

Kallman (2006) noted that in Hamburg, Germany alone, the city produces about 1.4 million tones, while in the United State of America, it produces 200 million tonnes of solid waste annually. A typical American generates waste an average of 2 kg of solid waste each day. Although Maisamari (2008) noted that the average is 3.5 kg. While according to Andrew and Simon (2004) In Dahiru (2003) over 70 million tonnes of waste are produced in the construction industry each year and it amounts to 24 kg/week for every person in the United Kingdom. In Nigeria, the annual per capital generation of solid waste had reached approximately 2.2 million tonnes (Maigari, 1999; AbdulGaffar, 2009). Today waste has become a nuisance in the lives of Nigerians because people tend to neglect or overlook the consequences of generating large amount of waste and not properly disposing it. There are no adequate equipment for effective evacuation of waste, no single engineered landfill and other disposal sites (Ibrahim, 2006). Besides that, industrial contaminants are discharged into streams and rivers without treatment, flaring of gas in industries and bush burning. All these have negative consequences.

According to Bokinni (2008) deficiencies in waste disposal is one of the major causes for the continuing high rate and also plays a role in vector-borne diseases. Unfortunately, result of a study shows that the world rubbish increment spread is 8.42% (AbdulGaffar, 2009). That is why according to Dahiru (2003) how to deal with and re-use of an increasing number of waste, has become an important topic in recent years. A lot of researches were undertaken on how waste can be re-used. Results of investigations showed that many of construction waste can be re-used as renewable material after sorting; removing or crushing e.g., scrap steel, scrap iron, scrap wire and various of scrap steel accessories can be re-processed into variety of steel products after sorting, collecting and re-melted down. Bamboo wood waste can be used in making of man-made timber. Brick, stone, concrete and other waste can replace sand after crushing and used for masonry mortar, plaster mortar, lit the concrete layer, etc. and also used to make brick, road brick, lattice brick and other building materials.

Polymer waste is increasingly becoming and environmental problem in Nigeria. They are essentially polyethylene packing bags and pure water bags which are used in large amount and constitute a high percentage of municipal solid waste around cities in

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Nigeria. This polymer waste is non-biodegradable and apart from degrading the environment, burning of this material as commonly practiced, as a means of waste disposal and this leads to emission of green gases. According to AbdulGaffar (2009) the safest, easiest and least expensive ways to reduce material waste production and disposed impact are to produce less, use less, re-use more and re-cycle everything possible of the millions of tonnes of garbage that are produced each year, in the whole world, it is estimated that more than 70% of it could be re-cycled.

This research examines the use of polymers waste known as "leather bags or pure water bags" as a partial replacement of fine aggregates in the production of concrete. This is particularly important in view of the observation made by experts that in future there would be no sand to be used for construction work (Shetty, 2004). This polymer has a common name of poly (ethylene oxide) or PEO and has an IUPAC name poly (oxyethene).

MATERIALS AND METHODS

Preamble: The study was undertaken in the concrete laboratory at department of building, Ahmadu Bello University, Zaria-Nigeria in the year 2012. The research involves two major steps. Firstly, preliminary investigation of some of the physical properties of constituents of concrete was carried out Secondly the actual study of evaluating the quality of concrete produced using PWM as partial replacement of fine aggregate in concrete production.

Materials: The materials used in this research include cement, water, fine aggregate, polymer, coarse aggregate.

Cement: The cement used is ordinary Portland cement manufactured by Dangote Cement Company Plc and the cement was recently supplied.

Fine aggregate: The Fine Aggregate used in this research work was fine river sand; it was obtained from the Department of Building Ahmadu Bello University, Zaria and sieved with a 4.75 mm B.S sieve.

Polymer Waste Material (PWM): The polymer waste material which includes, waste packing material was collected and taken to a local Polythene Recycling Company, Ebonite Strips and Conduit Pipe Manufacturing Industry (Rob Kusa Ltd.) at Dakata Kano, Kano State-Nigeria. Sieved with a B.S sieve of 600 micron-4.75 mm.

The collected polymer waste material was heated in an industrial plant until the material becomes crispy and hard, this is then passed in mechanical blender and grounders.

Coarse aggregate: The coarse aggregate was obtained from a quarry along Samaru-PZ near School of Aviation Technology, Zaria and supplied to the Departmental of Building Ahmadu Bello University, Zaria laboratory. It was sieved with a 10 and 20 mm sieve size to remove organic impunities and unwanted aggregate sites.

Methods:

Sieve analysis and determination of the melting point of PWM: The aggregate sample used for the experiment was fist, subjected to sieve analysis, while the Melting point of the Polymer Waste Material (PWM) was determined. The details are as follows.

Sieve analysis: The fine aggregate was graded by passing through BS sieve size 7 mm so as determine the grading curve.

Determination of aggregate melting temperature (paraffin wax test): The PWM was sieved, graded and measured into a small beaker or test tube, which was immersed in a beaker filled with paraffin wax and heat, was applied to the paraffin wax, until the aggregate in the test tube start to change in state (i.e., from solid to liquid) the temperature at this stage was recorded. This temperature is thus the melting temperature of the aggregate sample.

Preparation of sample:

Trail mix: For the fact that water/cement ratio influences the compressive strength of concrete, care was taken in the selection of suitable water/cement ratios to be used in the trial mix, taking into account the nature of aggregate. Test samples were prepared by first, undertaking a trial mix. Two water/cement ratios of 0.65 and 0.55, absolute volume method of batching and a mix ratio of 1:3:6 were used. A total of 12 cubes were produced for this purpose. Two sets of concrete 150×150×150 mm cubes were produced. First set of concrete cubes were prepared using cement, sand and coarse aggregates and serve as a control sample. While the second set consists of cement, coarse aggregates, sand and a varying percentage of fine aggregate/polymer (i.e., for 10, 20 and 30%, respectively). as a partial replacement of sand For each percentage substitution of PWM, 3 cubes were cast for the trial mix All cubes cast for trial mix were labeled A_0, A_h A_l, A_S.

Final mix design: In this final mix design, the absolute volume method of batching was also applied in determining the quantities of ingredients. Using a nominal mix proportion of ratio 1:3:6 (Cement: Sand: Gravel) and a water/cement ratio of 0.65. A total of 48 cubes were cast for the final mix design and 12 cubes were used for each of the four types of mixes, in the final mix. The procedure used remained the same for

Table 1: Concrete cube numbers and identification

	Trial mix design cubes		Final mix design	
PWM (%)	Identification mark	No. of cubes	Identification mark	No. of cubes
0	A_0	3	C_0	12
10	A_1	3	A	12
20	A_2	3	B	12
30	A_3	3	C	12
Total		12		48

Table 2: Quantity of materials required for a batch of six (6) cubes in kg

Percentage of PWN (%)	Quantity of PWM (kg)	Quantity of cement (kg)	Fine aggregate (kg)	Coarse aggregate (kg)	Water (kg)
0	-	4.39	14.64	27.64	2.85
10	1.46	4.39	13.18	27.45	2.85
20	2.93	4.39	11.71	27.45	2.85
30	4.39	4.35	10.25	27.45	2.85

Table 3: Quantity of materials required for a cylinder in kg-tensile test

Percentage of PWN (%)	Quantity of PWM (kg)	Quantity of cement (kg)	Fine aggregate (kg)	Coarse aggregate (kg)	Water (kg)
0	-	1.21	4.0	7.7	0.56
10	0.40	1.21	3.60	7.7	0.56
20	0.80	1.21	3.20	7.7	0.56
30	1.20	1.21	2.80	7.7	0.56

both the trial and final mixes. The preparation of the samples was carried out in accordance to the relevant British Standards such as BS 1881:125 (British Standard Institution BS 1881: 125, 1986). The four specimens representing 0%, (control sample), 10, 20 and 30% partial replacement of sand with the PWM were labeled C_0, A, B, C, respectively. The samples were removed from the mould after 24 h and cured inside curing tank at temperature of 18°-20°C for 28 days. Detail is shown in the Table 1.

Concrete cube test: For the fact that compressive strength is the most important property of concrete that is used to assess the quality of concrete, (Neville and Brooks, 2002), the cube samples were subjected to compressive strength test in accordance to the appropriate British Standards Besides that, the influence of PWM on the tensile strength of concrete was also measured by subjecting Cylinder samples prepared to tensile test.

Compressive strength test: At the end of 7, 14, 21 and 28 days, respectively of curing, the compressive test was carried out on each cube; 3 cubes were used for each of the 4 types of concrete samples. This amounts to 12 cubes for each curing day. The crushing machine used for the test was a compressive machine of 1100 kg capacity. It was used to determine the crushing load or failure load of the cube specimen. The machine applied load axially on the cube specimen at constant rate until a minimum load which corresponds to the ultimate compressive load was recorded as the failure load for that cube. The compressive strength of each cube was then calculated (Table 2).

Tensile strength test: In view of the low tensile strength recorded during a trial tensile strength test, it was only at the 28th day of curing, that tensile strength test was carried out. In which 3, 150×300 mm concrete cylinders were used for each of the 4 different samples, which equals to 12 cylinders. The tensile test was conducted, using the 1100 kg capacity testing machine. It was used to determine the failure load of the cylinder specimen subjected to tensile load at constant rate, until the samples fail. Details of the proportion of materials used per cylinder are shown in the Table 3.

RESULTS

Results of the sieve analysis in order to determine the grading of aggregate used, for the experiment, compressive strength test result and the tensile test are presented below.

Sieve analysis: Thus, it can be observed that 73.3% passed through the BS Sieve size of 9.5 mm while 14.7% were retained; this is in sharp contrast to 94.3% retained and 4.78% passing in BS Sieve size of 4.75 mm.

Melting point of PWM: The melting point of the PWM determined is the range of 150°-155°C.

Workability: Result of the workability test, below, shows that all the various mixes have very low degree of workability. Although, for concrete produced with a partial substitution of PWM, the mixes were relatively lower than the control sample (0% PWM). The workability reduces as the PWM content increases During the production of concrete it was observed that there was no proper coating between PWM and other ingredients-cement, fine aggregate, course aggregate and water. The samples made with partial replacement of PWM were very harsh (Table 4).

Table 4: Workability test result

PWM (%)	W/C	Slump (mm)	Degree of workability
0	0.65	23	Very low
10	0.65	12	Very low
20	0.65	8	Very low
30	0.65	5	Very low

Table 5: Sieve analysis

B.S sieve sites (mm)	Weight retained	Percentage passing	Percentage retained
9.50	105	73.30	14.7
4.75	154	4.78	94.3
2.36	1365	14.30	72.3
1.18	910	28.20	11.6
600 µ	495	15.40	4.7
300 µ	142	4.41	17.9
150 n	35	1.08	4.3
Pan	15	0.47	3.4

Compressive and tensile strength: From the results of both the tensile and compressive strength tests, it can be observed that there is wide gap between the results of the control samples and other samples made with partial replacement of PWM. This applies to both the compressive strength and tensile strength tests. For example the average compressive strength for the control sample is 26.3 N/mm^2 while for sample produced using 30% PWM as partial replacement of sand, it is 12.3 N/mm^2 this represent 53% difference.

The tensile strength test result also shows that there is wide gap between the control samples and sample produced using a partial replacement of PWM. For the average tensile strength of the control sample is 2.10 N/mm^2 while the tensile strength for sample made with 30% partial replacement of PWM, it is even below 1N/- just 0.56 N/mm^2, this represent 73.3% difference.

DISCUSSION ANALYSIS

The result of the tests conducted in this research are analyzed and discussed below.

Sieve analysis: Result of sieves analysis conducted for the research is presented in Table 5 as it can be observed from the table; 10.5 kg of B.S sieve sizes 9.5 mm aggregate was retained while 73.3 and 14.7 represent the percentage of aggregate passing and those that were retained, respectively.

While for the 4.75 mm B.S sieve sizes, the weight retained was 15.4 kg whereas, 4.78 and 94.3 represent percentage passing and those that were retained respectively. Looking at the result of the sieve analysis it shows that the distribution of sizes of aggregate is fair except for those retained below 300 micron B.S sieve thus, it can be said that the aggregate belong to zone one.

Melting point of PWM: The result of the test on the melting point of PWM shows that the maximum melting point is 155°C. This implies that concrete made of PWM as a partial replacement of fine aggregate, cannot be used where the structure will be exposed to high temperature above such temperature. Thus the concrete, most likely, has very low durability.

Workability: Looking at the result of workability test, it shows that the control sample has a slump of 24 mm while the other samples have slumps ranging from 12-5 mm. This shows that the degrees of workability for the entire samples are very low. However there is a wide gap between the slump of the control sample and other samples having certain proportion of PWM as partial replacement of fine aggregates. This shows that the higher the PWM content the less the workability. It implies that PWM has negative influence on the workability of the concrete sample. Besides that, more work is needed in order to make concrete produced with PWM as a partial replacement of fine aggregate sufficiently dense and consistent. Based on the observation made during the mixing it almost impossible to have concrete of uniform or good blend of all the ingredients.

According to Neville and Brooks (2002) concrete having very low degree of workability is suitable for roads, vibrated by power-operated or hand-operated machines. However when the melting point of PWM is taken into consideration, it may not be feasible to use such concrete for roads most especially in tropical regions like Nigeria.

Another major problem observed, was that the mix was very harsh and the water doesn't sufficiently mix with other ingredients to produce a uniform matrix (Fig. 1).

Compressive strength test: Table 6 and 7, show the result of compressive test carried out on each cube at 7, 14, 21 and 28 days, respectively of curing and from that result, it can be observed that, there is steady increase in strength with increase in days. However such increase varies. The rate of increase for the control cube is relatively higher than sample having partial replacement of fine aggregate with PWM. This shows the strength development is slower for concrete with PWM. This may be attributed to relatively high moisture content in the concrete sample observed, even after 28 days. Additionally, as the polymer material content increase, compressive strength reduces. This implies that as the polymer waste material increases as a partial substitute of sand in the concrete, the compressive strength decreases up to 53% for a partial replacement of 30%. This means PWM makes concrete weaker thereby reducing its quality.

Also the graph in the figure below illustrates the relationship between the compressive strength of both

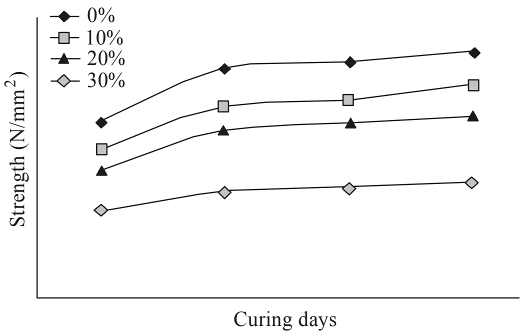

Fig. 1: Compressive for various mixes (0, 10, 20 and 30%, respectively PWM-content)

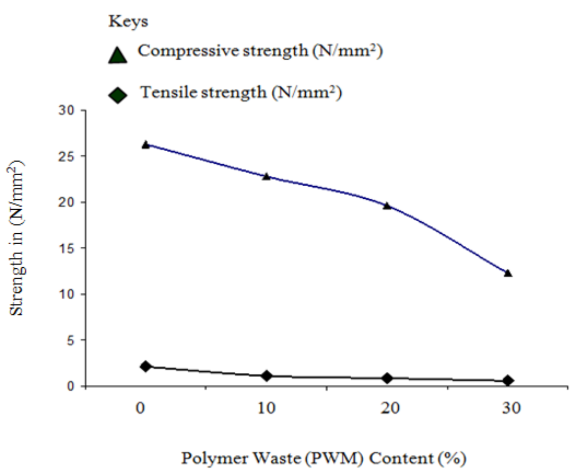

Fig. 2: Compressive and tensile strength at 28 days of curing

Table 6: Average compressive strength (n/mm^2) for various curing days

Curing days		Average compressive strength (N/mm^2)			
PWM content (%)	W/C ratio	7	14	21	28
0	0.65	18.7	24.5	25.3	26.3
10	0.65	15.9	20.5	21.2	22.8
20	0.65	13.5	17.9	18.7	19.5
30	0.65	9.20	11.3	11.7	12.3

Table 7: Compressive strength (N/mm^2)

Polymer content (%)	Water cement ratio	28 days compressive strength (N/mm^2) /Avg.
1	0.65	26.3
10	0.65	22.8
20	0.65	19.6
30	0.65	12.3

Avg.: Average

Table 8: Tensile strength (N/mm^2)

Polymer content (%)	Water cement ratio	28 days tensile strength (N/mm^2) /Avg.
0	0.65	2.10
10	0.65	1.10
20	0.65	0.84
30	0.65	0.56

Avg.: Average

the control sample and concrete with PWM at 28 days of curing with the tensile strength.

Tensile strength: Table 8 shows the result of tensile strength test carried out on the samples at 28 curing days, it can be deduced that as polymer materials content increases, the tensile strength decreases. This means there is an inverse relationship between the PWM and the tensile strength. Besides that the tensile strength is very low compared to the compressive strength. For, when the compressive is 26.3 N/mm^2 at 28 days of curing, the tensile strength was merely 2.10 N/mm^2, which is just about 8% of the compressive strength. Also, the compressive strength for samples having 20 and 30% partial substitution of fine aggregate with PWM, they are 19.6 and 12.3 N/mm^2 while the tensile strengths are 0.84 and 0.56 N/mm^2, respectively. This represents just about 4.3 and 4.6%. Although it may be argued that there is difference between cubes and cylinder, but when the modification factor is used to convert the values, it would be observed that there is still wide difference between the compressive strength and the tensile strength. This means PWM has no any positive impact on the tensile strength it rather weakens both tensile and compressive strengths. This is clearly depicted by the graph shown in Fig. 2, in which the curves slope or fall from left to right. Thus showing the higher the PWM, the less the strength.

CONCLUSION AND RECOMMENDATIONS

Conclusion: Based on the results obtained in this research, the following conclusions were drawn:

- The melting point of PWM is in the range of 150°-155°C which shows concrete made with PWM as a partial replacement of fine aggregate has low durability.
- The workability of both control sample and samples made of PWM as partial replacement of fine aggregate have very low degree workability and that PWM greatly influence the workability. The higher the PWM content, the less the workability.
- Water used for the mixing fails to mix properly with other ingredients-no proper coating.
- The compressive strength of samples decreases as the content of PWM increases, as a partial replacement of sand, in the concrete mix. Besides that, the strength development of samples containing PWM as a partial replacement of fine aggregate is relatively slow.
- There is also an inverse relationship between the tensile strength of concrete samples and PWM content. The higher the content of PWM, as a partial replacement of sand, in concrete, the less the tensile strength.
- The higher the polymer content the less, the higher its water retention capacity. Thus it has more hydrogen, as such, may have higher nuclear radiation attenuation capacity.

- An increase of 30% of PWM leads to decrease of 53% compressive strength and 73.3% decrease in tensile strength.

Recommendations:

- The PWM concrete should not be used for structural purposes.
- The PWM concrete should not be used in major. Construction pending further research on the performance of such concrete in service-such as test on durability.
- If PWM is to be used in concrete production, another means of processing Waste, PWM, should be investigated.
- Test should be carried out on use of PWM concrete as a shield from nuclear radiation.

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