Investigation into the Behaviour of Polymer-Aggregate Concrete under Compressive Loading Condition

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Abstract
The problem of Housing deficit has been a major problem in Nigeria owing to the perennial hike in prices of building materials in which cement, sand and granite form the nucleus of the materials in the built industry; hence the need to research into local available materials that could replace the conventional materials used in concrete production. This paper investigated the behaviour of a polymer concretes using Reprocessed Pure Water Sachet (PWS) as binder, laterite and clay as aggregates in separate mixtures with polymer for possible replacement of conventional cement concrete in some areas of application. The polymer aggregate concretes were prepared by mixing Reprocessed PWS with laterite and clay differently in different polymer-aggregate percentage replacements by volume (50%-50%, 60%-40%, 70%-30%, and 80%-20%) after sieve analysis had been carried out on aggregate samples. Compressive strength test was carried out on all samples after 28 days of air drying. It was discovered that polymer aggregate concrete compresses under a small applied load ranging from an average of 1.13KN to 1.88KN; and the loss in weight/height was alarming as the polymer (Reprocessed PWS) content in the concrete mix increases. It was also discovered that, the more the polymer content the lower the compressive strength in both cases, that is, laterite and clay aggregates but higher values were recorded in laterite but still a far cry from average compressive strength of reinforced concrete. The compressive strength ranged from 3.0N/mm^2-1.0N/mm^2 (50%-50% to 80%-20%) for laterite aggregate and 1.0N/mm^2-0.5N/mm^2 for clay aggregate. However, it was observed that polymer aggregate concretes behaved in such a manner that, under compression process, the samples didn’t break as always in the case of conventional cement concrete but a loss in weight and height were recorded owing to solvent oozing out of samples under compression process.
Keywords: Polymer Concrete (PC), Pure Water Sachet (PWS), Polymer-Aggregate, Sieve analysis, Compressive Strength.

1. Introduction

In the construction industry new building materials with improved properties are required for satisfying the new utilization domains for modern construction or for repair works. For years the development of the basic materials of concrete, with some minor exceptions, has been evolutionary rather than revolutionary (Mehta and Monteiro, 1993; Islam et al, 2011). True, since World War II, cement manufacturing and aggregate beneficiation equipment have undergone considerable improvement which has been reflected in greater uniformity and improved physical and chemical characteristics. But the basic components of the materials themselves have been changed very little (Mehta and Monteiro, 1993; Islam et al, 2011). In just the last decade or two, however, some radically new approaches to concrete have been introduced and tested. One of the newest is polymer concrete. The use of polymer concrete as a building material could represent savings in both material and labor cost (Mehta and Monteiro, 1993; Wahby, 2003; Islam et al, 2011). Development of polymer concrete has not advanced to the degree of widespread commercial application, but, as research produces improved techniques and better monomers, polymer concrete should be at the core of significant advances in concrete construction (Mehta and Monteiro, 1993).

Polymer concrete is formed by polymerizing a mixture of a monomer and aggregate with no other bonding material (Garas and Vipulanandan, 1997; Wahby, 2003; Ohama, 2006; Islam et al, 2011). To minimize the amount of the expensive binder, it is very important to achieve the maximum possible dry-packed density of the aggregate. The properties of polymer concrete are largely dependent on the amount and properties of polymer in the concrete. Polymer concrete presents some advantages compared to the cement Portland concrete such as: rapid hardening, high mechanical strengths, improved resistance to chemical attack, durability and the most important disadvantages is the high cost of resin that limited the use domains of polymer concrete(Mehta and Monteiro, 1993;Garas and Vipulanandan, 1997; Wahby, 2003; Ohama, 2006; Islam et al, 2011).Depending on the materials employed, polymer concrete can develop compressive strengths of the order of 140 MPa within hours or even minutes and is therefore suitable for emergency concreting jobs in mines, tunnels, and highways(Fowler, 1999; Abdel-Fattah and El-Hawary, 1999; Wahby, 2003).Thermal and creep characteristics of the material are usually not favorable for structural applications of polymer concrete. Due to good chemical resistance and high initial strength and modulus of elasticity, industrial use of polymer concrete has been mainly in overlays and repair jobs (Garas and Vipulanandan, 1997; Fowler, 1999; Abdel-Fattah and El-Hawary, 1999; Wahby, 2003; Islam et al, 2011).Polymer concrete is used for many kinds of specialized construction projects. Like other types of concrete, it can be used to join two different components or provide a structure or base. The material is used in electrical or industrial construction where the concrete needs to last a long time and be resistant to many types of corrosion (Wahby, 2003; Ohama, 2006; ACI, 2009).

According to Raji et al (2008), a laterized-polymer-cement concrete, however is polymer cement concrete which the fine aggregate which is usually fine sand has been replaced by a lateritic soil having an equivalent size as that of the fine sand. The use of laterite soil as fine aggregate was aimed at solving the problem of shortage of construction materials, since the soil is available in large quantities and in varying types all over Nigeria as well as in most parts of the tropical world, especially in Africa. This is essentially due to the fact that lateritic soils are products of tropical and sub-tropical weathering (Ola, 1983).

The use of lateritic soil in the construction of building is common in this country especially in the rural areas. Their use is also being encouraged in the urban areas of the country in recent times (e.g Mandate Housing Estate in Ilorin, 100 units of which were built with blocks made with lateritic soils) (Raji et al, 2008). In spite of the encouragement, there is still widespread skepticism about the behavior of the soil and hence acceptability among the growing middle class in Nigeria. This is primarily due to lack of publicity and well established standards regarding the performance characteristics of blocks and concrete made from stabilized and unsterilized lateritic soils (Raji et al, 2008).

In this research, laterite and clay were used separately, basically as the aggregates in the concrete mix with Reprocessed Pure Water Sachet as binder to produce polymer aggregate concretes i.e polymer laterite concrete and polymer clay concrete. The behaviors of the concretes were investigated under compressive loading condition in order to affirm their suitability in construction especially when subjected to serious loading conditions.

2. Materials and Methodology

The Polymer aggregate concretes were produced using "Pure water" sachet, organic solvent (Kerosene), and laterite and clay as aggregates in two separate mixtures with polymer. Though, the production exists in three forms namely; laboratory scale, pilot scale and the industrial scale; the pilot scale method was adopted.

The pure water sachets were collected within the Ilorin environs; the collected PWS was shredded and air dried to remove any form of moisture that could be present. The dried shredded pieces were heated on a burner by dissolving in a solvent (kerosene) at a temperature ranging between 200^oC – 300^oC and equally being stirred intermittently. Stirring continued as heating was in progress until homogeneity was achieved. The solution was poured in a calibrated cylinder and laterite aggregate added to it after sieve analysis had been carried out on it in accordance to ASTM D422-63 (2007) in four (4) different polymer-aggregate percentage replacements by volume (50%-50%, 60%-40%, 70%-30%, and 80%-20%). For each polymer-aggregate percentage replacement, the mixture was stirred evenly before being poured into 100mmx100mmx100mm metal concrete cube mould and allowed to cool and solidify for about 3 hours before being demoulded. This was allowed to cure for 28 days after-which compressive strength test was carried out on the sample in accordance to BS 1881, Part 1161. The same procedure as elaborated above was followed for polymer aggregate concrete using clays as aggregate. An average of four(4) samples were prepared for each percentage replacement, so, therefore, a total of 32 cubes were cast, that is, 16 cubes each representing 50%-50%, 60%-40%, 70%-30%, 80%-20% polymer aggregate replacements for both laterite and clay aggregates.

3. Discussion of result

The result revealed that the percentage weight reductions of polymer clay concrete in 50%-50%, 60%-40%, 70%-30%, 80%-20% polymer aggregate percentage replacements are 2.96%, 6.26%, 10.36%, 14.70% respectively; while the percentage weight reductions of polymer laterite concrete in the same polymer aggregate percentage replacements as above are 1.83%, 3.07%, 11.18%, 11.83% respectively. It could be deduced that the more the polymer content in the concrete mix, the more the weight loss under compression process; but was higher in polymer clay concrete when compared with polymer laterite concrete at each polymer aggregate percentage replacement and, this might not be unconnected to the variation in gradation of the aggregates (laterite and clay) as it was noticed that laterite contained more coarse particles as against clay with more of fine particles. And the weight of the coarse particles which are more prevalent in laterite could have made the difference.

The result also showed under compression process, the percentage reductions in the height of polymer clay concrete are given as 7%, 12%, 20%, 28% for the different polymer aggregate percentage replacements in order of 50%-50%, 60%-40%, 70%-30%, 80%-20% respectively; while polymer laterite concrete has its percentage height reductions in order of 11%, 18%, 24%, 31% for the different polymer aggregate percentage replacements in similar order as stated above. It could also be deduced that the more the polymer content in concrete mix, the more alarming the reduction in the height of polymer concrete under compression process; but at each polymer aggregate percentage replacement when compared together, unlike as in the case of weight reduction above, the height reduction was more significant in the polymer laterite concrete and this could be as result of the tendency of coarse particles to crush under compressive force/load which will in turn reflect in the reduction in the height of such object as the coarse particles prevalent in laterite reduce in size. And as reported earlier, laterite contained coarse particles than clay. Therefore, it could be safe to say the more the polymer content in concrete mix, the more the reduction or loss in weight or height of samples.

Also, the polymer clay concrete compressed at an average compressive load of 1.13KN as against polymer laterite concrete which compressed at an average compressive load of 1.88KN. This lends credence to the superiority of polymer laterite concrete over polymer clay concrete as earlier asserted/affirmed in terms of weight.

In terms of density, the result showed that polymer clay concrete has density values of 809Kg/m^3, 799Kg/m^3, 579Kg/m^3, 471.5Kg/m^3 for the different polymer aggregate percentage replacements of 50%-50%, 60%-40%, 70%-30%, 80%-20% respectively while the polymer laterite concrete has density values of 1281Kg/m^3, 879Kg/m^3, 706Kg/m^3, 589Kg/m^3 for the same/similar polymer aggregate percentage replacements as expressed above. When compared together, polymer clay concrete has an average density of 665Kg/m^3 while polymer laterite concrete has an average density of 864Kg/m^3. This has also lent credence to the superiority of polymer laterite concrete over polymer clay concrete; but have their maximum densities of 1281Kg/m^3 and 809Kg/m^3 respectively short of conventional cement reinforced concrete (Grade 25) density of 2400Kg/m^3 as according to Oyenuga (2008).

The compressive strength test showed that polymer clay concrete has concrete strength in order of 1.5N/mm^2, 1.5N/mm^2, 1.0N/mm^2, 0.5N/mm^2 for the different polymer aggregate percentage replacements of 50%-50%, 60%-40%, 70%-30%, 80%-20% respectively while polymer laterite concrete has strength in order of 3.0N/mm^2, 2.0N/mm^2, 1.5N/mm^2, 1.0N/mm^2 for the same polymer aggregate percentage replacements as above. Therefore, polymer clay concrete has an average compressive strength of 1.13N/mm^2 while polymer laterite concrete has an average compressive strength of 1.88N/mm^2. Similarly, their maximum compressive strengths of 1.5N/mm^2 and 3.0N/mm^2 respectively fall short of conventional cement reinforced concrete (Grade 25) with an average compressive strength of 25N/mm^2 as according to BS8110 1(1997) and Oyenuga (2008). It could also be deduced that the more the polymer in the concrete mix, the lower the density and compressive strength of polymer aggregate concrete. However, reverse is the case for conventional cement concrete as the more the binder (cement) in a concrete mix, the more or higher the density and compressive strength of such concrete.

It has been observed that according to some researchers who had worked on polymer concrete affirmed the superiority of polymer concrete over cement concrete in terms of rapid hardening, high mechanical strengths, improved resistance to chemical attack, durability but following the result of this study reverse is the case most especially in terms of strength. Therefore, it would not be right to just say polymer concrete is better than cement concrete in terms of properties listed above but could be better depending on the type of polymer concrete or category of polymer concrete under review simply because polymer concrete as described in some quarters are of different classes as reported by Pomeroy and Brown (1995). They affirmed that there are four classes of polymer concrete materials in the construction industry, depending on the types of monomers used in the concrete. The classes include polymer impregnated concrete, polymer cement concrete, polymer concrete and lastly, partially impregnated and surface coated polymer concrete. This research falls in the third category of polymer concrete, that is ‘’polymer concrete’’ which is a composite concrete containing polymer as a binder instead of the conventional Portland cement. However, all these classes of polymer are referred to as polymer concrete but owing to the variation in their formation, their properties would never be the same most especially in terms of strength.

The relationships between the compressive strength and percentage mix of polymer clay concrete and polymer laterite concrete are presented in tables 1 and 2 while Sieve analysis results of both polymer concretes are presented in tables 3 and 4.

4. Conclusion

Following the results of the study, it can be concluded that polymer aggregate concrete under compressive loading condition behaves in the following ways;

- It compresses under a small applied load ranging between an averages of 1.13KN to 1.88KN.
- It experiences continued weight loss and height reduction as polymer content increases.
- It exhibits continued loss in strength and density as polymer content increases.
- It doesn’t crush under compressive loading condition as in conventional cement concrete but instead, it reduces in height/weight as solvent oozes out of it when subjected to compressive loading condition.

- Based on the behavior of polymer concretes under consideration, they are suitable for use in areas where strength is of less concern, that is, areas where it is not expected to resist any or direct load such as in patch and repair, decorative cement overlays, ceramic tile adhesives, and many others.

References

Abdel-Fattah, H and El-Hawary, M. M. (1999) ‘’Flexural Behavior of Polymer Concrete’’ Construction Building Materials, Volume 13(5), 253-262.

ACI 548. IR-09:’’Guide for the Use of Polymer in Concrete, Chapter4-Polymer Concrete’’, reported by ACI Committee, pp.11-16., 2009.

ASTM D422-63 (2007)’’ Standard Test Method for Particle Size Analysis of Soils. Active Standard ASTM D422/ Developed by subcommittee: D 18.03

BS 1881. Part 116, Method for determination of Compressive Strength of Concrete Cube. British Standard Institution. London.

BS 8110 1-1997: Structural Use of Concrete- Part1: Code of Practice for Design and Construction. British Standard Institution. London.

Fowler, D.W (1999) ‘’Cement and Concrete Composites’’ International Journal of Cement Composites and Lightweight Concrete, Volume 21, Issues 5-6, Pp349-468.

Garas, V.Y and Vipulanandan, C. (1997).’’Review of Polyster Polymer Concrete Properties: Centre for Innovative Grouting Materials and Technology (CIGMAT), Department of Civil and Environmental Engineering, University of Houston, Houston, TX 77204-4003.

Islam, M.A., Rahman, M.M., and Ahmed, M. (2011) ‘’ World Experience and Potential for Bangladesh’’, The Indian Concrete Journal.

Mehta,P.K. and Monteiro, P.J.M (1993). Concrete: Structure, Properties, and Materials, Prentice Hall, Technology & Engineering-548pp.

Ohama, Y., (2006) ‘’ Recent Trends in Research and Development of Polymer-Modified Mortar and Concrete in Japan’’ Proceedings of the 5th Asian Symposium on Polymers in Concrete, Volume 1, Structural Engineering Research Centre, CSIR Campus, Chenai, India, pp. 3-11

Ola, S.A (1983) ‘’ Geotechnical Properties and Behaviour of some Nigeria Lateritic Soils, in Tropical soils of Nigeria in Engineering practice (Edited by S.A. Ola) Balkema, Rotterdam.

Oyenuga, V.O. (2008)’’Simplified Reinforced Concrete Design (A Consultant/Computer-Based Approach)’’, Second Edition, Vasons Concept Engineering Series, Astros Ltd, Surulere, Lagos, Pp1-412.

Pomeroy, C.D. and Brown, J.H.(1995) ‘’ An Assessment of some Polymer (PMMA) Modified Concrete’’ Proceedings, First International Congress on Polymers in Concrete London, U.K

Raji, S.A., Abdulkareem, S.A, Ibrahim, A.O. (2009) ‘’Effects of Reprocessed Polythene Water Sachets (PWS) on strength and permeability of laterized concrete. Journal of Research Information in Civil Engineering, Centre point (Science Edition) Vol.6, No.1

Wahby, W.S. (2003) ‘’ Fifty years’ history of polymer in concrete in Review, ACI International, Publication-SP 214-2, Pp. 13-14

Table1: Compressive strength test result of polymer clay concrete

% Ratio of PWS-Laterite	Average weight before compaction (g)	Average weight after compaction (g)	Average height before compaction (mm)	Average height after compaction (mm)	Average compressive load (KN)	Compressive strength (N/mm^2)
50-50	809	785	100	93	1.5	1.5
60-40	799	749	100	88	1.5	1.5
70-30	579	519	100	80	1.0	1.0
80-20	589.2	402	100	72	0.5	0.5

Table2: Compressive strength test result of polymer laterite concrete

% Ratio of PWS-Laterite	Average weight before compaction (g)	Average weight after compaction (g)	Average height before compaction (mm)	Average height after compaction (mm)	Average compressive load (KN)	Compressive strength (N/mm^2)
50-50	1281	1257.5	100	89	3.0	3.0
60-40	879	852	100	82	2.0	2.0
70-30	706	627	100	76	1.5	1.5
80-20	589.2	519.5	100	69	1.0	1.0

Table 3: Results of sieve analysis of lateritic soil sample (1000g)

B.S sieve size (mm)	sieve weight(g)	sieve+sample retained(g)	weight of sample retained.(g)	weight of sample passing(g).	% passing
8	568	568	1	999	99.9
4	550	632	82	917	91.7
2.36	424	538	114	835	83.5
1.7	419	484	65	721	72.1
1	516	661	145	656	65.6
0.5	487	716	229	511	51.1
0.4	472	509	37	282	28.2
0.3	322	368	46	245	24.5
0.25	464	639	175	199	19.9
0.15	311	391	80	24	2.4
0.063	440	488	48	*	*
pan	393	426	33	*	*

Table 4: Result of sieve analysis of Clay soil sample (1000g)

B.S sieve size (mm)	sieve weight(g)	sieve+sample retained(g)	Weight of sample retained.(g)	weight of sample passing(g).	% passing
2.36	427	430	3	997	99.7
1.7	413	425	12	985	98.5
1	520	539	19	966	96.6
0.85	430	451	21	945	94.5
0.5	491	532	41	904	90.4
0.4	416	549	133	771	77.1
0.3	326	360	104	667	66.7
0.25	410	450	140	527	52.7
0.212	357	401	144	383	38.3
0.09	452	505	153	230	23
0.063	401	492	97	133	13.3
0.05	405	420	25	108	10.8
0.03	404	428	33	75	7.5
pan	401	433	41	34	3.4