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STRUCTURAL RESPONSE OF HEATED POLYMER REINFORCED CONCRETE FAÇADE TO LOADING

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Abstract: The recycling of used materials is now very common all over the world, in order to save the environment from pollution. This paper looked into how used-polyethylene material can be effectively recycled for construction purposes and the effect of temperature on the end products. The used polyethylene sachets were converted to 6mm diameter polymer rod under controlled temperature and pressure. Two sets of five samples concrete façade of size 500 x 300 x 30 mm was cast using the polymer rod and steel respectively. Some of the slabs were exposed to a temperature of 50^{0}C for six hours, after which they were subjected to loading until failure occurred. At ambient temperature, crack width, was 0.40mm and 0.30 mm; maximum deflection, 5.99mm and 12.25 mm; and ultimate failure load, 2.50 kN and 2.70 kN for steel and polymer rod slabs respectively. While at 50^0 C, crack width was 0.7mm and 1.3mm, deflection, 11.2mm and 12.72 mm, and ultimate failure load, 5.3 kN and 3.00 kN for steel and polymer respectively. Polyethylene (polymer) rod could be a very good substitute in slender concrete structures like façade because of its low crack width, non-corrosive nature and it low thermal conductivity.
Keywords: Polyethylene sachet, Concrete Façade, Polymer rod, Deflection, Crack width

INTRODUCTION

Concrete reinforced with fibre reinforced polymer (FRP) materials has been under investigation since the 1960's. Unstressed FRP reinforcement has been developed in a number of forms including ribbed FRP rod similar in appearance to deformed steel reinforcing bar, un-deformed E-glass and carbon fibre bar bound with polyester, vinylester or epoxy resin, E-glass mesh made from flat FRP bars and prefabricated reinforcing cages using flat bars and box sections (Gowripalan,1999). Stressed FRP reinforcement is also available, usually consisting of bundles of rods or strands of fibre-reinforced polymer running parallel to the axis of the tendon. These are used in a similar fashion to conventional steel tendons (Gowripalan, 2000). The durability performance of FRP reinforcements is considered by some (Gowripalan, 1999, Ko, 1997) to offer a possible solution to the problem of corrosion of steel reinforcement, a primary factor in reduced durability of concrete structures. Other reported advantages of FRP rebar include enhanced erection and handling speeds (Karbhari and Zhang, 1999) and suitability to applications which are sensitive to materials which impede radio wave propagation and disturb electromagnetic fields.

A polymer is a large molecule (macromolecule) composed of repeating structural units typically connected by covalent chemical bonds. Whereas the term polymer is sometimes taken to refer to plastics, it actually encompasses a large class of natural and synthetic materials with a wide variety of properties.

Natural polymeric materials such as shellac, amber, and natural rubber have been used for centuries. A variety of other natural polymers exist, such as cellulose, which is the main constituent of wood and paper. The list of synthetic polymers includes synthetic rubber, Bakelite, neoprene, nylon, PVC, polystyrene, polyethylene and many more (Wikipedia, 2011). The attractive forces between polymer chains play a large part in determining a polymer's properties. Because polymer chains are so long, these inter-chain forces are amplified far beyond the attractions between conventional molecules. Different side groups on the polymer can lend the polymer to ionic bonding or hygrogen bonding between its own chains. These stronger forces typically result in higher *tensile strength and higher crystalline melting points (Omnexus.com, 2011).*

The intermolecular forces in polymers can be affected by dipoles in the monomer units. Polymers containing amide or carbonyl groups can form hydrogen bond between adjacent chains; the partially positively charged hydrogen atoms in N-H groups of one chain are strongly attracted to the partially negatively charged oxygen atoms in C=O groups on another. These strong hydrogen bonds, for example, result in the high tensile strength and melting point of polymers containing urethane or urea linkages (Omnexus.com, 2011).

Over the last decades, used water sachet that is made of polyethylene materials have become nuisance to the environment because of it non-biodegradable property. Several times when the water in the sachet is used up, the waste sachet is found in drains and other water ways which has led to flooding.

Many works have gone into the use of Fibre Reinforced Polymer (FRP) by Sivagamasundari and Kumaran (2008). Also Hegger et al (2010) investigated the advantages of textile reinforced concrete applied to a pedestrian bridge in Germany, and the results concluded that it is possible to design slender and light weight concrete members by using technical textiles instead of steel as reinforcement. A small number of new loads bearing civil engineering structures have been made predominantly from FRP materials over the last three decades. These include compound curved roofs (Hollaway, 2002), pedestrian and vehicle bridges and bridge decks, energy absorbing roadside guardrails (Bank and Gentry, 2000), building systems, modular rooftop cooling towers (Barbero and GangaRao, 1991), access platforms for industrial, chemical and offshore (Hale, 1997), electricity transmission towers, power poles, power pole cross-arms and light poles and marine structures such as seawalls and fenders (Weaver, 1999).

Some codes like the ACI code and CAN/CSA code allow the use of Glass Fibre Reinforced Polymer (GFRP) bars as main reinforcement for concrete structures such as bridge decks, floor slabs and wall type structures. (ACI committee, 1996, CAN/CSA-S6-02, 2002).

The aim of this research work is to use polyethylene sachets used in the packaging of water as an alternative reinforcement in concrete façade. And the objective is to determine the flexural behavior of reinforced concrete façade at both ambient and elevated temperature.

MECHANICAL PROPERTIES OF POLYMER

The tensile strength of a material quantifies how much stress the material will endure before suffering permanent deformation (Ashby and David, 1996, Meyers and Chawla, 1999). This is very important in applications that rely upon a polymer's physical strength or durability. For example, a rubber band with a higher tensile strength will hold a greater weight before snapping. In general, tensile strength increases with polymer chain length and cross-linking of polymer chains. A High Density Polyethylene HDPE has a strength between 25-30mpa and a Low Density Polyethylene LDPE has a strength of between 10-20mpa (omnexus.com, 2011).

Young's modulus quantifies the elasticity of the polymer. It is defined, for small strains, as the ratio of rate of change of stress to strain. Like tensile strength, this is highly relevant in polymer applications involving the physical properties of polymers, such as rubber bands. The modulus is strongly dependent on temperature (Ashby and David, 1996, Meyers and Chawla, 1999). Table 1 showed the mechanical properties of each reinforcement.

Table 1: Properties of reinforcement

No	Reinforcement type	f (N/mm^2)	E_s (N/mm^2)	D_f (mm)	Strain ε	No. of reinforcements
1	Polyethylene	30	1,110	6	0.02703	18 bottom
2	Steel rod	250	200, 000	6	0.00125	4 bottom

where: f = Tensile strength of reinforcement, E_s = Modulus of elasticity of Reinforcement, D_f = diameter of reinforcement, ε = Strain of reinforcement at ultimate load.

MATERIALS AND METHOD - POLYETHYLENE ROD PRODUCTION

The polyethylene rods were made from sachets water packs. The packs were gathered in large amount, washed and spread to drain the water *from it. After the water had been drained, they were taken in a bag to a polyethylene bag manufacturing company in Lagos Nigeria.*

The sachets were introduced into intake of the extrusion machine after the temperature and the pressure for the melting had been set on the control panel of the extrusion machine. As the sachets were introduced into the intake, the sachets start melting and then came out from the mould at the mouth of the extrusion machine in rod form of 6mm diameter.

As the rods come out, a water bath is provided where the rods were made to go through so as to cool off the temperature and make it harden. Figures 1-2 showed the process.

Figure 1: Polyethylene rod coming out of the machine

Figure 2: The Polyethylene rod in water bath.

PRODUCTION OF REINFORCED CONCRETE FAÇADE

The façade were designed based on the tensile strength of the reinforcing materials, mild steel rod with strength of 250 N/mm² and polyethylene rod of 20 N/mm² were used for the design of the slab prototypes. Both the steel and the polyethylene rods were arranged based on the design specifications which gave the diameter of the material and the spacing, for the polyethylene rod, 18 number 6 mm rod was used at a spacing of 25 mm for both ways, while for steel rod 4 number 6 mm rod at 125 mm spacing was applied at both ways. The reinforcing materials were then placed into the wooden mould (i.e. form work). These formworks are 500 mm by 300 mm by 30 mm in to in. There were a total of ten (10) number concrete façade produced from the experiment, five number each for the Steel and polyethylene rods respectively. The concrete mix used was 1:2:4 i.e. the proportion of 1 part of cement to 2 parts of fine aggregate and to 4 parts of coarse aggregate while the water-cement ratio (the w/c ratio) was 0.5 i.e. 1 part of water to 2 parts of cement by weight.

The concrete was well mixed, the cement, fine and coarse aggregate were measured through the use of weighing balance i.e. batching was by weigh. Ordinary Portland cement was used and the fine aggregate was the sharp sand. The size of the coarse aggregate used was half an inch (12 mm).

The moulds were lubricated with oil before concrete was poured into it to allow easy removal of the slab specimens after it is set. After the preparation of thoroughly mixed concrete, it was then poured into the moulds and then compacted or vibrated manually by shaking the moulds. The slab specimens were removed from the mould after it has been allowed to set for 24 hrs. The slabs were then cured to gain full strength by pouring water on it everyday. After 28 days, the slab specimens were put into test.

It is possible for stresses to be induced by temperature changes in composite members which are additional to those produced by applied loads. These stresses arise when the components of a composite member have different rate of thermal expansion. Two samples each from the steel and polymer reinforced facades were exposed to a temperature of 50 ^{0}C (an average temperature for a desert area) for about six hours before crushing, while others were left at room temperature, the specimens were placed in a testing machine in such a manner that the load was applied at the top surface and supported on all four sides. The axis of the specimen was carefully aligned with the axis of loading device. The digital dial gauge attached to the retort stand was placed on the slab close to loading point to measure the deflection due to the *applied load and load was also gradually increased by the adjusting knob at an interval and the corresponding deflection was recorded. The specimen was loaded until it failed, the ultimate failure load was recorded and the crack width was measured at failure load.*

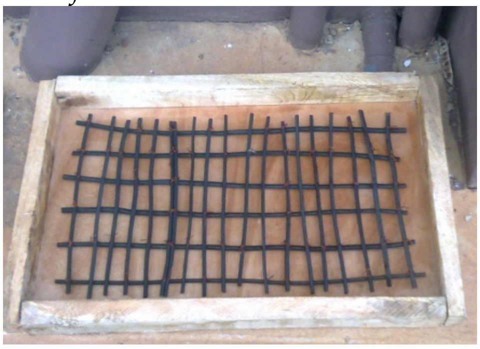

Figure 3: Polyethylene rod in mould

RESULTS

At room temperature of 25 ^{0} C, it was observed in the steel reinforced façade that the cracks started from the centre which was the point of loading and gradually moved toward the corner edges of the slabs as the load was increasing, the crack width at failure load was 0.40 mm. The deflection of the slabs in this group increases slowly as the load increases and the elastic limit was exceeded when the load got to 2.30 kN and finally failed at 2.50 kN. Figure 4 showed the graph.

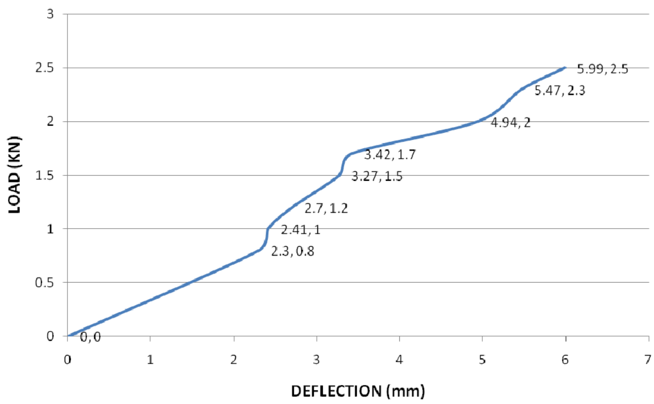

Figure 4: Deflection for Steel reinforced façade at room temperature

The results for the slab reinforced with polyethylene showed that the failure occurred at the centre which has the point of load and the crack pattern is very similar to that of the slab reinforced with steel but with a crack width of 0.30 mm. The deflection of the slabs in this group increases rapidly as the load increases forming a curve but there was a sharp change of direction at 1.90 kN while the elastic limit was exceeded at 2.25 kN, the gradual curve continues until it finally failed at 2.70 kN. Figure 5 showed the deflection pattern.

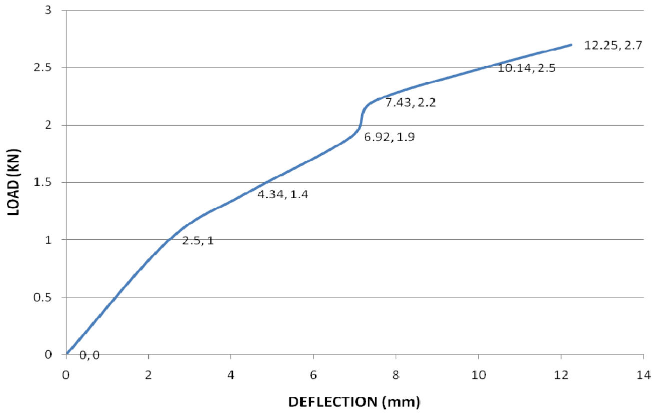

Figure 5: Defelction for Polyethylene rod façade at room temperature

At higher temperature of 50 ^{0}C after six hours, the crack width for steel reinforced facades was 0.70 mm, the deflection was 11.20 mm while the slab failed at 5.30 kN load. Figure 6 showed the graph of load against deflections.

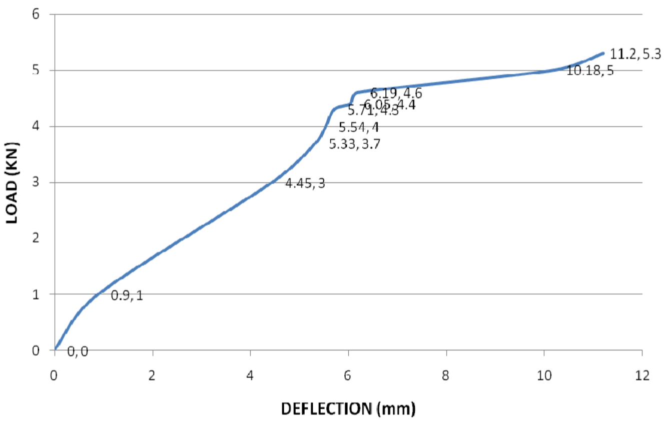

Figure 6: deflection of Steel façade at 50 ^{0}C

For the polymer reinforced slab, crack width was 1.30 mm, deflection was 12.72 mm and failure load was 3.00 kN. The graph is showed in Figure 7. The above results showed that increasing the temperature of slabs has effect on its properties, the failure load for both type of slab increased with temperature, with that of steel reinforced façade increasing by over 100%, which implies that the increment in temperature corresponds to the increase in the strength of the reinforced concrete as far as the melting point of the concrete material is not reached, this is a confirmation that the older the concrete, the stronger it becomes. This theory is based on the facts that the water content in the concrete is reduced as the temperature increases, and this will lead to the increment in the bonding *between all the aggregates that made up the concrete.*

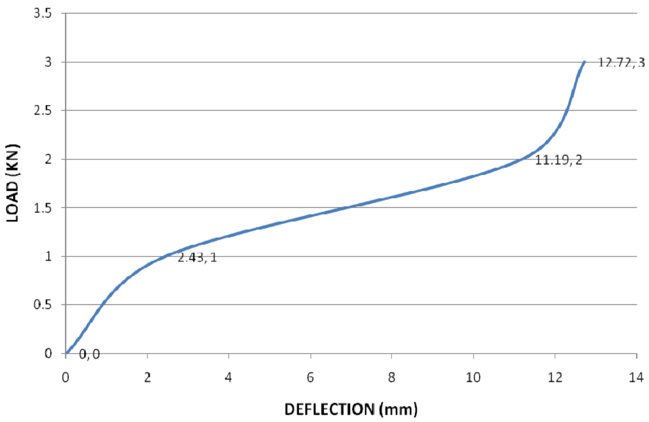

Figure 7: Deflection of Polymer rod façade at 50 ⁰C

The increment in temperature led to increase in deflections and crack widths; these can be traced to the reinforcement used in both type of slabs. Steel exhibit weakness when exposed to temperature, and this is as a result of it higher thermal conductivity, that was why the deflection in steel reinforced façade increased by 87%, when compared with polymer reinforced façade which increased by a marginal 4 %.

CONCLUSIONS

At ultimate load, the polyethylene rod slab has a lower crack width when compared with steel reinforced slab at room temperature; this is a good advantage when considering the effect of water ingress that may cause corrosion in the slab element, also the resistance of polyethylene to water also gave it advantage over steel. There was no rupture in any of the two types of reinforcement used but they both failed at different yield point, with the steel reinforced slab failing earlier than the polyethylene rod slab at room temperature, this must have been due to the number and spacing of reinforcement used for each type of slab. The impact of temperature increase affected the performance of steel reinforced façade, with the fact that steel has a higher thermal conductivity than the polymer rod. The steel reinforced facade deflected more than it corresponding polymer façade, this is a disadvantage, because deflection can lead to excessive cracking, which will encourage the ingress of moisture into the concrete material, and by this action, corrosion will quickly set in and it will reduce the life span of the façade. Based on this study and the performance of polyethylene reinforced slab, the new material can be a good substitute to steel in slender structures like concrete façade. The low tensile property of the polyethylene rod can be improved upon in the nearest future through the use of nanotechnology.

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