Flexural Response of Reinforced Concrete Waffle Slab with Recycled Polyethylene Terephthalate (PET) in the Topping

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Abstract— The current trend of indiscriminate dumping of plastic wastes has lead researchers to look into the reuse of these materials especially in the building industry. In this work, waste plastic bottles polyethylene terephthalate (PET) were recycled to 4 mm diameter polymer rod and were used to replace wire mesh in the topping of waffle slab. The flexural strength and deformation of 12 waffle slabs with sizes of 700 mm × 700 mm × 120 mm, and 800 mm × 800 mm × 120 mm were determined with three samples for each size. The topping of six slabs were reinforced with the polymer rod while the remaining six were reinforced with wire mesh which served as the control. The laboratory test carried out showed that the young modulus of elasticity for polymer rod and wire mesh was 12,766 N/mm^2 and 30,469 N/mm^2 respectively. The average crack width for the waffle slabs reinforced with polymer rods and wire mesh range from 1 mm to 2.3 mm having maximum deflection of 42.93 mm and 40.64 mm respectively. The average ultimate flexural load was 50KN for both samples. The study concluded that the polymer rod could be used as topping in waffle slab.

Keywords— Plastic waste, Polymer rod, PET, Waffle slab, Wire mesh.

1. Introduction

The search for alternative material in reinforced concrete has led to many discoveries, since steel which has been the major materials in reinforced concrete have been found to get corrode easily when exposed to weather conditions, together with its very high cost. Some of the materials that have been used in place of steel bars in concrete are Fiber Reinforced Polymers (FRP), Glass Fiber Reinforced Polymers (GFRP), (Atutis *et al*, 2013; Gudonis *et al*, 2013; Timinskas *et al*, 2013). Most of these materials have been found to be good but will require some modifications before it can take the place of iron steel in construction. The durability performance of FRP reinforcement is considered by some to offer a possible solution to the problem of corrosion of steel reinforcement (Gowripalan, 1999; Ko, 1997). The advantages of FRP which included enhanced erection and handling speed was discussed by Karbhari and Zhang (1999).

In order to improve the performance of reinforced concrete, fibers modeled from recycled polyethylene terephthalate (RPET) can be used instead of steel bars when light reinforcement is required in achieving good result (Banthia and Sheng, 1996). The current applications of RPET in the construction industry is its use as resin for polymer concrete and synthetic coarse aggregate for lightweight concrete (Kim *et al* , 2008). These types of application have usage limitation in the construction industry due to the difficulty of mass production. In order to overcome the limitation, numerous studies are currently ongoing. One of the solutions to this limitation is using RPET as reinforcing short fibers in concrete to improve structural performance (Kim *et al*, 2008).

RPET has been investigated by many researchers, especially in it use in concrete and mortar, Ries *et al* (2011), used PET waste from beverage container as partial substitute for aggregate in concrete mortar, at 5%, 10%, 15% and 20%. The fractured properties of the obtained composite was investigated, and the work observed that the post-peak flexural properties of the mortar improved by the addition of PET, and the work concluded that the material can be used to partially replace aggregate in concrete mortar. Ochi *et al* (2007), developed and used PET fibers as concrete reinforcing fibers, it was observed that the PET fiber was alkali resistant, and the wetting tension was found to be low when compared to other polymer. Silva *et al* (2005) investigated the durability of RPET fibers embedded in cement based materials, mechanical test were carried out on the material, while the mortar was analyzed by spectrum Electron Microscopy (SEM), the work concluded that PET fibers have no significant influence on mortar strength and elastic modulus, the SEM test supported the conclusion from the mechanical test.

Won *et al* (2010) investigated the long term durability performance of RPET fiber reinforced concrete composite, Chloride permeability, repeated freeze-thaw test were conducted, the work revealed that RPET fibers reinforced composite were not different from plain concrete in terms of chloride permeability. The repeated freeze-thaw test showed excellent endurance characteristics of RPET fiber reinforced composite. Kim *et al* (2008) researched into the effect of the geometry of RPET fiber reinforcement on shrinkage cracking of cement based composite, the work showed that the fiber geometry and fraction by volume did not affect total moistures loss, but increased fractions of RPET resulted in improved control of the plastic shrinkage cracking.

Foti (2013) carried out some test on concrete specimens reinforced with fibers made from PET bottles; the fiber was used as discrete reinforcement of specimens and little beams in substitution for steel bars. The result obtained was very encouraging and suggesting a possible use of this material in form of flat or round bars in structural reinforcement. Akinyele and Olatomide (2014) used polymer rod made from low density polymer to determine the structural characteristics of heated solid slabs facade, the work concluded that the low crack width developed in the façade will make the

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polymer rod a good substitute in such structure. The aim of this work is to examine the structural use of RPET as alternative to wire mesh in the toppings of reinforced concrete waffle slab.

2. Materials and Method

2.1 Polymer Rods

The polymer rod used for the topping of the waffle slab was produced from PET bottles. The PET bottles were gathered in large quantity from various points and bulks of it were collected at a waste dump in Lagos, Nigeria. The label around the bottles were removed, the bottles were thoroughly washed and allowed to dry before bagging and transporting them to a polythene factory. The bottles were introduced into the intake of the grinding machine which grinded them into smaller pebbles normally called lumps in the polythene industry. The lumps were then bagged and transported to another polythene industry where the lumps were further recycled. The lumps were introduced into the intake of a machine called extrusion/palletizing machine. The machine was set at a temperature of 180^0C .The intake of the extrusion machine received the lumps and began to melt it. The melted lumps began to come out from the moulds of the extrusion machine in rods form of 4 mm diameter as shown in Plate 1. A large basin of water was provided very close to the extrusion machine to receive the hot rods as they were coming out so as to cool down the temperature. The rods were made to pass through the second basin of water very close to the first one in order to harden and solidify it, the rod were finally removed from the water and placed in a clean platform.

The ultimate tensile strength is the maximum stress that a material can withstand while being pulled before breaking. The recycled polymer rod and the wire mesh used in this work were taken to a Universal testing machine (UTM, Okhat, 600 kN, 2012 model) in order to examine their tensile strength. The testing involves taking a small sample with a fixed cross-sectional area, and then placed on the machine under a constant force until the sample gets to it breaking points.

Plate 1: Polymer rod coming out of the extrusion machine

2.2 Form Work

The formwork was made of wooden planks and boards. The formwork was constructed having the following dimensions, 700 mm x 700 mm x 120 mm, 800 mm x 800 mm x 120 mm for the various sizes of the slab produced. The mould used for the hollow of the waffle slab was produced using polystyrene of size 150 mm by 150 mm; the polystyrene was joined to the base of the form work with glulam and well aligned so as to get perfectly straight ribs in both directions. Prior to placement of reinforcement bar and concrete, all rubbish were removed from the interior of the form work. The face of the formwork in contact with the concrete was cleaned and treated with release agent (grease oil), Plates 2 and 3 showed the samples of formwork used.

Plate 2: Formwork for polymer rod waffle slab

Plate 3: Form work for wire mesh waffle slab

2.3 Waffle slabs Size

Two sizes (700 mm × 700 mm, and 800 mm × 800 mm) of waffle slab were produced with minimum of three samples for each size making total of 12 slabs. The slabs were reinforced according to the structural design. The twelve specimens of waffle slabs were prepared and the ribs of all the slabs were reinforced with 2Y8 steel bars at the bottom. The recycled polymer rods were used as the top reinforcement for six samples while the remaining six which serves as control were reinforced with wire mesh at the top. Waffle slabs were design in line with BS 8110 (1999).

Prior to usage, reinforcement was taken from where stacked and was free from mud, oil, paint, and loose rust which can weaken the bond of concrete. The steel rod used for the rib portion of the waffle slabs has yield strength of 460 N/mm^2 in accordance with BS 449 standard (2002). The bars were rigidly fixed in correct position to prevent displacement during concreting.

Before placement of the concrete, the form works were primed with oil so as to enhance easy removal of the concrete. The fresh concrete mix for each sample was fully compacted by tamping rod, to remove trapped air, which can reduce strength of the concrete. Since the hydration of cement does take time, the concrete was cured for 28 days by covering it with jute sack and by sprinkling water on it to achieve its potential strength and durability.

2.4 Flexural strength Test

Flexural strength also known as modulus of rupture is defined as a material's ability to resist deformation under load. After curing and de-moulding of the form work, the waffle slabs were moved to the load cell machine in the laboratory for flexural test. According to BS EN 12390: 5 (2009), four points loading was adopted for all the sizes of the slab. Slabs of sizes 800 mm x 800 mm x 120 mm were tested with the waffle side pointing upward while slabs of sizes 700 mm x 700 mm 120 mm were tested with the waffle side turned upside down this was to allow for the determination of tensile forces at both the slab and rib portion of waffle slab. Two rollers were placed under the specimen at both edges while two were placed at the top in an equidistant manner. The specimen was placed in the load cell machine in such a way that the load was applied at the central surface of the specimen through a device called hydraulic power jack. The axis of the specimen was well aligned with the axis of the loading device.

Three dial gauges of 0.01 mm precision were mounted under the machine with the tip of the gauges placed on the specimen to measure deflection. The first dial gauge placed at the right side measured deflection D1, the second dial gauge placed at the center measured deflection D2 while the third dial gauge at the left side of the specimen measured deflection D3. The load was applied gradually through the power jack at every 5 KN and the corresponding deflections were measured and recorded. The specimen was loaded to failure and the applied load at failure causes crack to develop under the slab. No initial crack was observed for all the specimen and the final cracks were well distributed across the specimen. The crack width for each specimen was measured using vernier caliper. Plates 4 and 5 showed the slab setup.

Plate 4: Loading of slab samples

Plate 5: positioning of dial guages.

2.5 Crack Width Measurement

The experimental and theoretical crack width for each slab samples were determined, the development of cracks in concrete structures are very important, cracks can develop as a result of loading, creeps, temperature, shrinkage and other circumstances. The theoretical crack width was determined using Equation 1. While the experimental crack widths were determined at failure load using digital veneer caliper, of sensitivity up to 0.01mm.

$$\frac{3a_{cr}\varepsilon_m}{1+2\left(\frac{a_{cr}-C_{\min}}{h-x}\right)} \qquad (1)$$

3. Results and Discussion

3.1 Mechanical Properties of Reinforcements

The mechanical properties of both the wire mesh and polymer rods were determined from a universal testing machine. The tensile strength of a material quantifies how much stress the material can withstand before failure, while the young modulus quantifies the elasticity of the materials. From the results in Table 1, The young modulus of the wire mesh is more than that of the polymer rod by over 100%, this implies that the elasticity of the polymer rod is very low when compared to that of the wire mesh, and this may be a disadvantage to it use in other types of slabs apart from waffle slabs that has reinforced ribs which provided the required strength for the slab. But using it at the top slab portion in waffle slab may be of a very good value to the aim of this work, since the slab topping of waffle slab only support compressive loading in the slab.

Table 1. Mechanical properties of reinforcements

S/N	Reinforcement Type	Tensile Strength *(kN)*	Stress σ	Strain ε *(N/mm²)*	Young Modulus *(N/mm²)*	Diameter *(mm)*
1	Polymer Rod	5.22	415	0.0325	12,766	4
2	Wire mesh	7.48	1,523	0.05	30,460	2.5

3.2 Flexural Strength Test Results

The results of the flexural tests showed that waffle slab of size 800mm x 800mm reinforced with polymer have maximum deflection of 40.13 mm with maximum crack width of 2.6 mm at failure load of 50 kN. The result of the same sizes reinforced with wire mesh has maximum deflection of 40.69mmwith maximum crack width of 2 mm at the applied load of 50 kN, the slab portion of this size was placed under tensile load.

The waffle slab of size 700mm x 700mm reinforced with polymer has maximum deflection of 42.93 mm with maximum crack width of 1mm at the applied load of 50 kN. The result of the same sizes reinforced with wire mesh has maximum deflection of 38.86 mm with maximum crack width of 1 mm at the applied load of 50 kN, the rib portion of this slab size was placed under tensile force.

From Figures 1 to 4, the deflections of the polymer reinforced waffle slabs are generally higher than that of wire mesh reinforced slabs, this can be attributed to the low modulus of elasticity of the polymer rod. The failure loads for the two samples with different dimensions are the same. The implication of this development is that the waffle slab ribs play a major role in the integrity of a waffle slab structure, while the slab portion with the different reinforcement distributes the loads to the ribs, and provide structural stability. Since the polymer rod is used in the toping of the waffle slab in this experiment, coupled with the positive results obtained, the material can be used for the intended purpose of replacing wire mesh in waffle slab toppings.

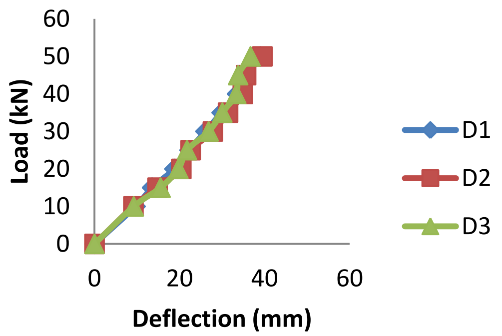

Fig. 1: Deflection of 800 x 800 mm polymer reinforced waffle slab.

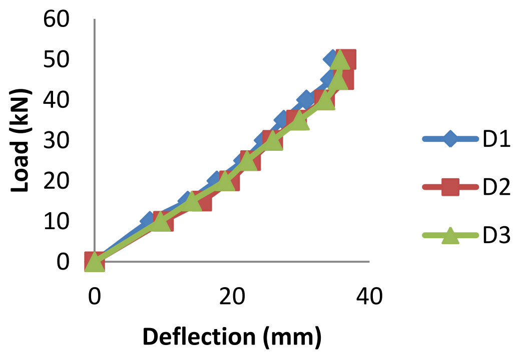

Fig. 2: Deflections of 800 x 800 mm wire mesh waffle slab

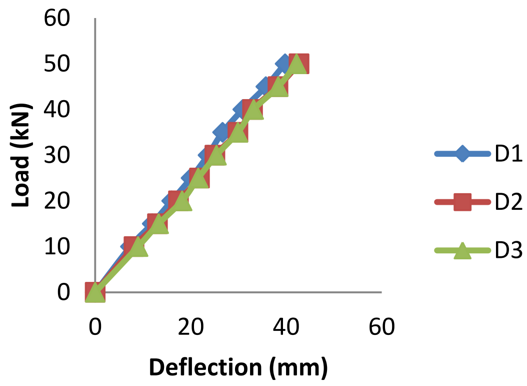

Fig. 3: Deflection of 700 x 700 mm polymer waffle slab.

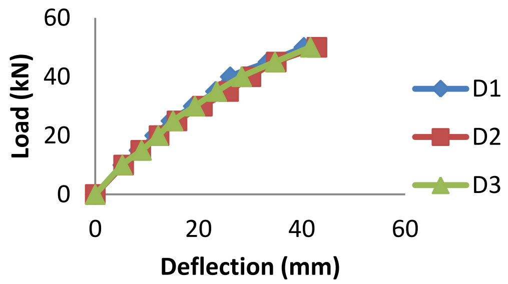

Fig. 4: Deflection of 700 x 700 mm wire mesh waffle slab.

3.3 Crack Width Results

The ductility of the reinforced concrete structure was also of paramount importance because any member should be capable of undergoing deflection at near maximum load carrying capacity (Teo *et al*, 2006). Members subjected to bending generally exhibit a series of distributed flexural cracks even at working load. These cracks are un-obstructive and harmless unless the widths become excessive, in which case appearance and durability suffer as the reinforcement is exposed to corrosion (Mosley and Bungey, 1999).These cracks were analyzed theoretically and experimentally, the results of the crack width for the prototype slabs were recorded in Table 2. It can be seen from the result that slab 800 × 800 mm reinforced with wire mesh has an average crack width of 1.92mm while the one reinforced with polymer rod has an average crack width of 2.3mm.

Slabs of sizes 700 × 700 mm reinforced with wire mesh has an average crack width of 1mm. while same sizes of slab reinforced with polymer rod also has an average crack width of 1mm. The use of recycled polyethylene terephthalate (RPET) as reinforcing bars in structural concrete can provide greater crack control and ductility; enhance the capacity for quasi-brittle concrete, which is a very important issue in the merit of recycling waste materials.

Table 2. Failure crack widths

Slab Sizes (mm)	Materials	Theoretical Crack width (mm)	Experimental Crack width (mm)
800 x 800	Wire mesh	0.06	1.92
800 x 800	Polymer rod	0.06	2.30
700 x 700	Wire mesh	0.06	1.00
700 x 700	Polymer rod	0.06	1.00

4. Conclusion

The use of polymer rod as alternative to wire mesh have been examined in this work, it was discovered the modulus of elasticity of the wire mesh is over 100 percent greater than that of the polymer rod, the deflection of the entire slab specimen that contains both material exhibited similar elastic behaviors as presented in the results, hence; the performance of the polymer material in waffle slab when compared to the wire mesh reinforced waffle slab showed that the polymer rod can perform well when used as topping in waffle slab, the material can be used for the intended purpose of replacing wire mesh. Although, the bond strength between the concrete and the polymer rod was not investigated, this should be the next focus in the research for alternative to wire mesh or steel rod in concrete.

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