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Original Research Article

Effect of Epoxy Resin on the Strength Propery of Portland Cement Concrete

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Abstract

In this study, the strength effect of partially substituting Portland Cement (PC) with epoxy-resin in making concrete was examined. A mix ratio of 1:1.87:2.67 (PC: sand: granite chippings) at water-cement ratio of 0.5 targeting a strength of 30N/mm^2 was adopted. The epoxy resin was mixed with hardener at a proportion of 1:0.5 and this mixture was used to replace PC at 10% intervals starting from 0% to 40%. Six cubes were cast for each mix ratio and were cured in water at room temperature for 28 days. The first set of samples were treated by heating them in an oven to a temperature of 100^{0}C for 1 hour before testing in compression while, the other set were not treated. Results showed that as the quantity of epoxy resin in the concrete enlarged the compressive strength values reduced. But a rise was observed at 30%. All concrete produced were structural in nature except for the heated 40% specimen. An optimal replacement strength of 32.10 N/mm^2 at 30% inclusion (unheated) and lowest strength of 18.63 N/mm^2 at 40% replacement (heated) were obtained. The heated samples experienced further reduction in their compressive strength values. An 8.94% drop in strength was observed between the maximum replacement values for the heated and unheated samples at 30%. In conclusion, epoxy resin concrete can be used for structural works at replacement levels up to 40%. However, if the concrete will be exposed to increased temperature of 100^{0}C, then an optimal replacement level of 30% is recommended.

Keywords: Compressive strength, hardener, temperature rise, replacement level.

1. INTRODUCTION

The building material known as concrete is very trendy in the construction industry and is mostly used in erecting both large and small infrastructures. It is already a known fact that this composite material is primarily made from aggregates, water, and cement. The cement which is the material that helps to join other materials in the mixture together and generate strength, can be produced in almost all countries of the world since the raw materials for making it are naturally very available (Adul-Wahab *et al.*, 2020). However, one major challenge of making this cement is that the process is not environmentally friendly since a lot of carbon dioxide is released into the atmosphere. The increase of this gas in the airspace is generating higher barometrical temperature with the negative ozone layer depletion effect following. Hence, any process that will help reduce the release of more carbon dioxide into the air with respect to concrete production is very much welcomed.

The extensive use of epoxy plastics in the various fields of life has led to the problem of plastic waste disposal. Dumping these waste materials at landfills/dump sites and the method of burning all contribute to environmental pollution which can be very dangerous to human health and living (Qi *et al*., 2023). Poisonous compounds from this plastic waste can infiltrate into the soil and contaminate plants and groundwater which human ingest thereby leading to deadly diseases that may sometimes be cancerous.

The use of traditional building materials like the conventional concrete is becoming inadequate in meeting up to the requirements of advancement in technology (Qi *et al.*, 2023). In constructing many modern infrastructures having innovative designs and concepts, very special properties of concrete are required which the nominal concrete cannot achieve. To solve or reduce the negative effects associated with concrete production and epoxy plastic waste disposal, all kinds of modified concrete that can meet up to the need of the times are being studied. One innovative and sustainable way in which concrete can be adjusted is by adding some amount of polymer into it.

Polymer-modified concrete is typically created by mixing polymer supplements with regular concrete. Water-soluble polymers, polymer powders, liquid resin, and latexes are a few types of these additives (Fernandez-Ruiz *et al.*, 2018). The inclusion of these additives in the concrete mix has been observed to improve chemical resistance, strength, durability and bond characteristics of mortar and concrete. Initially, this type of concrete was adopted for use as non-load bearing and for repair work but are presently being applied to structural works (Fernandez-Ruiz *et al*., 2018). Epoxy resin, which is a type of polymer can be used to replace some amount of cement in the concrete production process.

The polymer material termed epoxy solidifies into surfaces. They can be applied as a finish or as an element of glue. Its lightweight property, together with its impermeable and beneficial physical features, makes it a desirable substance that may be utilised in electronics, cars, aeroplanes, building, concrete surface restoration, and hydropower infrastructure strengthening (Dotson, 2018). Epoxy resins function effectively as adhesives for metals, wood, polymers, and other materials. Even while it is resilient in most common situations, extreme heat and moisture mixed with heat may trigger its matrix to deteriorate.

According to Dotson (2018), a considerable portion of epoxy's flexural and compressive strength declines with temperature rise. Epoxy reaches its Heat Distortion Temperature (HDT) at 60^0C, at which point it starts to distort. More ductile behaviour follows from raising the temperature to about 90^0C. Higher temperature additionally triggers an impairment of stiffness and ability to support loads. As a result, epoxies are vulnerable to temperature rise.

Epoxy concrete, also known as epoxy-modified concrete (EMC), is a composite material where ordinary Portland cement is partially replaced with epoxy resin, resulting in enhanced mechanical properties and durability (Mehrab, 2022; Qi *et al*., 2023). Epoxy concrete can be used to create high-strength structures with improved resistance to corrosion and chemicals (Kuan *et al*., 2022). Studies have shown that the inclusion of epoxy in concrete can increase its ultimate load capacity and improve crack resistance, especially in beams with poor bond conditions (Fouad *et al.*, 2021). Additionally, it exhibits superior fatigue resistance compared to traditional concrete, making it a promising material for various construction applications, such as highway pavements and long-span steel deck pavements (Mahmoud *et al.,* 2021).

The use of epoxy in concrete formulations offers a cost-effective solution for producing durable and high-performance composite materials for infrastructure project. According to Huang & Chen (2021), epoxy resin concrete can be used in the construction of bridge slabs, repairs of pavements and for special concrete pavement works. They have low temperature crack resistance, good durability, good bond with original concrete and higher temperature stability when compared to asphalt concrete. But, its behaviour under elevated temperature remains a topic of on-going investigation.

It is crucial to understand how environmental conditions, especially high temperatures, affect epoxy concrete's behaviour to guarantee its future dependability and safety. Compared to cement, which is an industrial substance, the organic resins used as binders in polymer concrete are more heat sensitive. Based on reports, the hottest temperature at which epoxy, and polyester concretes can be used is roughly 60 °C when exposed repeatedly and 100°C –120 °C when heated briefly (Oussama *et al*., 2012).

Research on the field of epoxy modified concrete have proved that this new innovative practice is viable. Fernandez-Ruiz *et al*., (2018), studied the durability and compressive strength properties of concrete with cement content partially replaced by epoxy resin and ground rubber. They produced two types of epoxy concrete, one set contained epoxy resin and hardener while the other set had no hardener in them. Cement was substituted at 10%, 15% and 20% respectively for all mix considered. They observed that the compressive strengths of the concrete were all lower than that of the control mix except for the composite that had a 20% replacement of cement with no hardener in it. Concrete produced were more ductile and those without hardeners had better durability quality against chloride attack than their control mixes.

Huseien *et al.,* (2023), investigated on the use of Epoxy Resin polymer as a self-healing cementitious material agent in mortar. The epoxy used contained hydroxyl-ion. They stated that the best mechanical property of the mortar was at 10% cement replacement with epoxy resin. The setting time and water absorption characters of the concrete reduced as the quantity of the epoxy rose. Substitution level greater than 10% led to a drop in the strength performance of the mortar. The study by Qi *et al*., (2023), revealed that to improve the tensile, compressive, and thermal resistance of concrete, recycled epoxy plastic sheets fibres can be introduced into the mix. The plastic sheet fibres were used as a substitute for sand at 5%, 10%, and 15% correspondingly. Concrete produced had strong cohesion since they did not slump. The high strength of compressive strength values obtained was attributed to the high bonding between fibres since the sheets were crushed into smaller granular sizes. Optimum percentage replacement was observed at 10%.

Similarly, He *et al*., (2023), worked on the topic, *Performance of concrete with recycled epoxy plate waste as a partial replacement for fine aggregate*. In their work, they replaced sand with three categories of particle size of the crushed recycled epoxy resin plate. Sizes investigated were 4mm, 4mm - 9mm and 9mm respectively. Best values were obtained at 10% replacement for particle size 4mm -9mm. But, as the quantity of the fibre increased beyond this level, strength began to drop. This reduction happened because of the hydrophobicity of the epoxy fibre. Also, the smooth surface of epoxy resin and fibre, developed a weak bond with mortar. Density of the concrete reduced as the quantity of the of recycled epoxy resin fibre increased. This occurred because the density of the fibre was less than that of the sand. Slump improved with higher amount of the fibre in the concrete.

2. MATERIALS AND METHODS

In this work, the materials and methods adopted are discussed as follows.

2.1 Materials

The main materials used are epoxy resin, hardener, superplasticizer, Portland cement, water, fine and coarse aggregates. The Bi-phenol A epoxy resin and hardener were procured from a chemical store situated at SARS road in Port-Harcourt, Nigeria. Physical and chemical properties of the epoxy resin are shown in Table 1. Superplasticizer with band name "Armocel 200 was purchased from a chemical store at Mile 3 in Port-Harcourt. It is a non-chloride, polycarboxylate based super plasticizer. The physical property of this material is presented in Table 2.

The Portland limestone cement produced by Dangote was acquired for the study. This cement generally conforms to the Nigerian Industrial Standard (NIS 444-1, 2003) for cement manufacturing. Fine aggregate in the form of river sand was obtained from the Choba river, Port-Harcourt. Meanwhile, the coarse aggregate i.e. granite chippings were purchased from the granite depot at Choba, Rivers State, Nigeria. Both soil type were found to be poorly graded (ASTM D-2487, 2011).

Table 1: Physical and chemical properties of the epoxy-resin

Property	Value	Property	Value
Physical state	Liquid	Freezing point	-16^{0}C
Appearance	Liquid	Solubility	6.9mg/l in 20^{0}C water
Odour	mild	Flash point	266^{0}C (at 1013hPa)
colour	Light yellow	Density	1.16-1.8g/cm^3
Vapour pressure	4.6E-8Pa @ 250^{0}C	Octanol H_20 coefficient	3.242
Relative vapour density	<1g/cm^3	Vapour temp.	25^{0}C
Boiling point	320^{0}C	Viscosity	7000-10000 cps
Melting point	-16^{0}C (at 1013hPa)		

Source: (REDOX, 2024)

Table 2: Physical property of the superplasticizer

Density	pH	Air entrainment	Specification
1.25g/cm^3 ± 0.01	7-9	< 2%	ASTM C494 Type C

Source: (ASTM C494, 2017)

2.2 Methods

The experimental methods observed in this investigation include specimen production, sieve analysis of the aggregates, slump test of the fresh concrete, bulk density test on cured concrete, and compressive strength test on unheated and heated cube samples.

a. Specimen production

A nominal concrete mix of 1:1.87:2.67(cement:sand:chippings) at water-cement ratio of 0.5 targeting 30MPa concrete was designed for. The mix ratio was then used to proportion the materials for manufacturing the concrete by weight as illustrated in Table 3. Portland cement was substituted by epoxy-resin in percentages of 10%, 20%, 30% and 40%. The mix having no epoxy-resin was taken as the control. The epoxy resin used to replace Portland cement was prepared by combining 1 part of epoxy-resin to ½ part of hardener by weight.

Superplasticizer of constant mass of 0.23kg (i.e. 1.5% of 50kg of cement) was adopted for all the mix. Six concrete cubes measuring 150mm x 150mm x 150mm were prepared for each mix ratio generating a total of thirty (30) cubes. The samples were demoulded after 24 hours and cured in water at room temperature for 28 days. Three cubes of each mix proportion were immediately subjected to compressive strength test while the other 3 cubes were heated at a temperature of 100^{0}C for 1 hour before being tested in compression.

Table 3: Mix proportion by mass for one concrete cube specimen

Mix ID.	% Substitution	Epoxy resin (kg)	Hardener (kg)	Super-plasticizer (kg)	Portland cement (kg)	Water (kg)	Sand (kg)	Granite (kg)
EC1	Control	_	_	0.23	8.33	2.57	14.63	29.93
EC2	10%	0.55	0.28	0.23	7.50	2.57	14.63	29.93
EC3	20%	1.11	0.56	0.23	6.66	2.57	14.63	29.93
EC4	30%	1.67	0.83	0.23	5.83	2.57	14.63	29.93
EC5	40%	2.22	1.11	0.23	5.00	2.57	14.63	29.93

b. Slump and bulk density test of concrete

The slump test was measured in accordance to BS EN 12350-2 (2019), and results obtained are presented in Figure 1. Bulk density of all the specimen were determined by measuring the mass in kilogram of the surface dry specimen and dividing it by its volume in meters. Values obtained can be seen in Table 4.

c. Compressive strength test

Compressive strength test according to BS EN 12390-3 (2019) was conducted on both heated and unheated specimen and the results determined are illustrated in Figure 3.

3. RESULTS AND DISCUSSION

The various results obtained from this investigation are shown in this section.

i. Slump

Values of the slump of each of the concrete mix ratio experimented are illustrated in Figure 1.

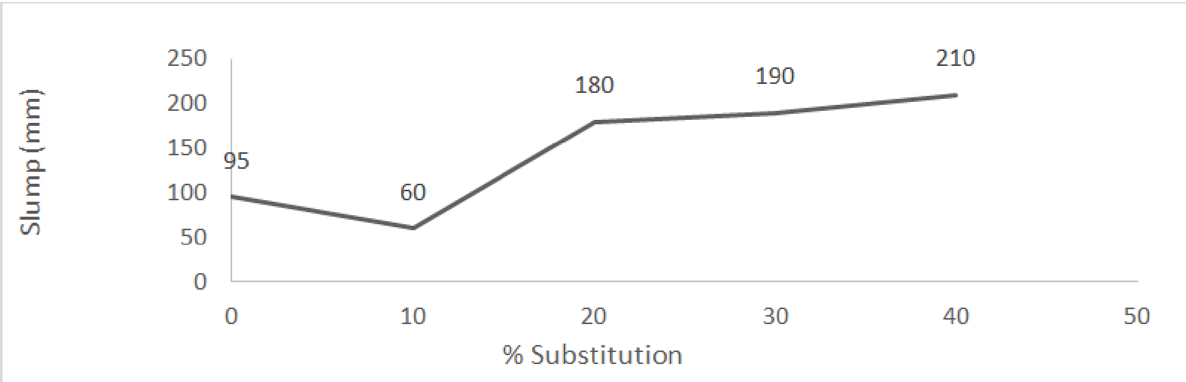

Figure 1: Slump of wet concrete at various replacement levels of Portland cement

It can be observed that mix EC1 (0% replacement) and EC2 (10% replacement) both produced a medium slump concrete which is very adequate for less workable ends and manual compaction of reinforced concrete structures BRE (1997). However, the mixes at 20% to 40% were all very wet. This occurred because as the quantity of epoxy resin increased, the cement content dropped while the quantity of the superplasticizer was still constant for all the mix ratios. This result suggests that in preparing an epoxy-concrete, the water-cement ratio must be carefully specified since the addition of more and more epoxy resin in the mix improves slump. For concrete with up to 20% inclusion of epoxy resin, there may not be the need to add superplasticizers depending on the water-cement ratio adopted and the type of slump required

ii. Density of the concrete

Table 4 displays the calculated surface dry bulk density for each sample along with the percentage differences between the unheated and heated specimen.

Table 4: Bulk density of specimen

% Replacement	Bulk density for unheated samples (kg/m^3)	Bulk density for heated samples (kg/m^3)	% Difference
0	2493.43	2323.55	6.81310484
10	2457.87	2429.73	1.144893749
20	2457.87	2425.19	1.329606529
30	2428.64	2397.14	1.297022202
40	2444.64	2434.47	0.416012174

Generally, the densities of the heated samples were slightly lower than that of the unheated ones. This was because of the loss in weight of the cross-linked epoxy polymer when exposed to high temperature (Oussama *et al*., 2012). As the quantity of epoxy resin increased in the mix, the density of the concrete was not really altered for both heated and unheated specimen. However, a very slight reduction was noticed. Furthermore, the epoxy resin concrete produced were all normal weight concrete (i.e. from 2200 to 2500kg/m^3). This type of concrete is very adequate for construction and offers a balance between workability and strength (Nirbhavane *et al.*, 2024).

iii. Compressive Strength

Compressive strength values of the different samples produced are illustrated in Figure 2.

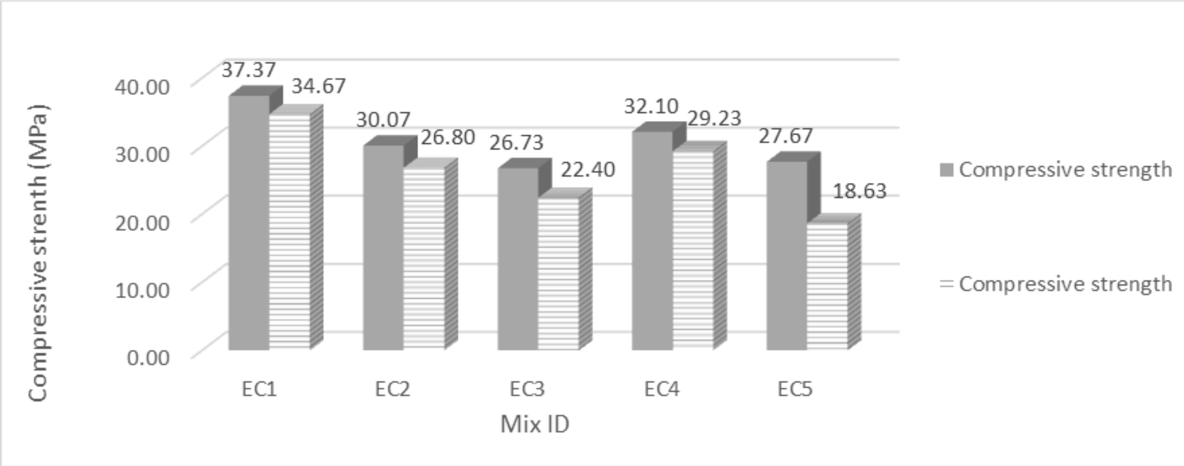

Figure 2: Comparison of the compressive strength of unheated and heated samples

Overview, the inclusion of epoxy resin in the concrete composite led to the decrease of the compressive strength of all specimen when compared to the control mix as seen in Figure 2. This may be accounted for due to the smooth surface of the epoxy resin forming a weak bond with the cement matrix and the presence of entrained air within the cement paste (He *et al*., 2023; Tripathi, 2024). Also, there is the possibility that full setting of the epoxy in the concrete mix may have occurred long before the cement could be fully hydrated leading to reduced strength. Therefore, the method for the preparation of this type of concrete must be given great attention since the materials; portland cement and epoxy are of different phases.

It was observed that the percentage difference between the compressive strength of unheated sample to their corresponding heated specimen indicated a further decrease in compressive strength for all the Mix ID. Specifically, the percentage differences reveal that at control (i.e. 0%, 10%, 20%, 30%, and 40% replacements, the compressive strength of the epoxy concrete decreased by 7.23%, 10.87%, 16.20%, 8.94%, and 32.67%, respectively. As the content of epoxy increased and the quantity of cement reduced, the compressive strength dropped with temperature increase up to 100^{0}C.

This trend agrees with the statement by Dotson (2018), that a significant amount of the compressive and flexural strength of concrete is lost with an increase in temperature due to the epoxy experiencing some level of distortion at temperatures up to 60^{0}C. According to Oussama *et al*., (2012), this distortion is because of the thermo-oxidative deterioration of the epoxy polymer and the dissociation between binder and aggregates. Increasing the temperature more than 60^{0}C will reduce the ability of the epoxy-concrete to carry load. However, the magnitude of strength derived were all structural in nature for all samples except for the heated sample at 40% substitution. Only Mix EC1 (both unheated and heated) and unheated mix EC2 and EC4 samples were able to attain a compressive strength up to 30N/mm^2. EC4 heated was very close to the stipulated strength at 29.23N/mm^2. The remaining samples fell below the target strength.

It is evident that the mixture with a 30% replacement exhibited the highest average substitution strength of 32.10N/mm^2 which is about 86% of the strength of the control mix for the unheated sample and 29.23N/m*m*^{2} (84% of the control mix) for the heated one. This optimal replacement level tallies with the findings by Jokhio *et al.*, (2021). They stated that there was a continuous decrease in the average compressive strength of epoxy concrete produced with silica as fine aggregate between 10% to 20%. Nevertheless, a rise in strength was observed at 30% replacement with an approximate strength of about 68% of the control. This could be due to the fact that the lower proportion of epoxy resin less than 30% did not produce enough of its own binding force (Jokhio *et al.*, 2021). At 40%, the strength started to recede again, but the strength of the unheated specimen was still greater than those at 20% replacement. The composite with a 20% replacement demonstrated the lowest average strength of 26.73N/mm^2 for the unheated sample while the 40% substitution produced a minimum strength of 18.63N/mm^2 for the heated sample.

iv. Relationship between compressive strength and density.

Figure 3 presents the relationship between compressive strength of the unheated samples with respect to their bulk densities.

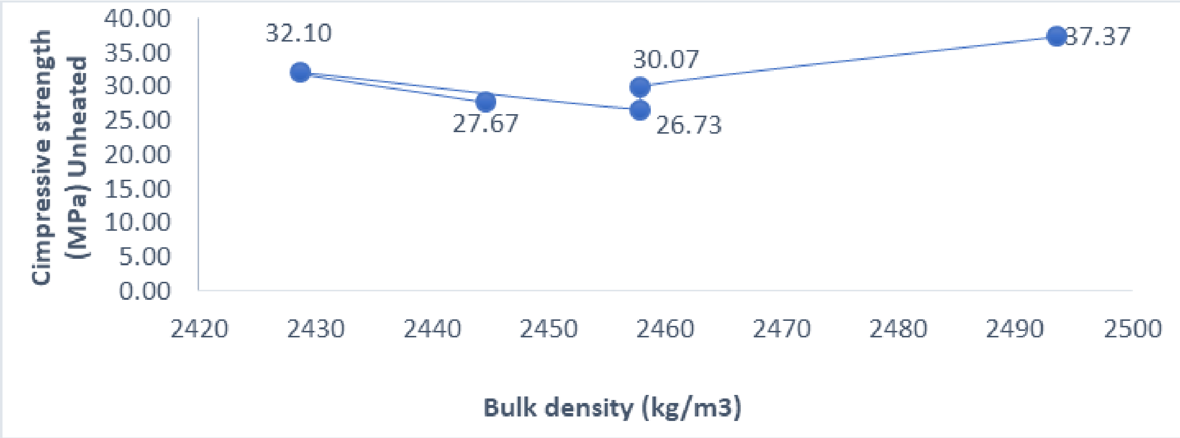

Figure 3: Relationship between compressive strength (MPa) and bulk density of concrete (kg/m^3) (unheated specimen)

Generally, as the density of the unheated samples reduced very slightly, with more inclusion of epoxy resin, the strength dropped. But, between 20% and 30% substitution, a rise in strength of about 20% was observed even though the density dropped. This was followed by a decline in strength of about 13.8% between 30% and 40% replacement. In between 10% and 20%, the density of the concrete was constant however, a reduction in strength of about 11.11% was observed.

From Table 4, the compressive strength of the heated concrete kept reducing as the density of the concrete dropped. In addition, the specimen which were treated by heating experienced higher density and strength reduction than the unheated samples.

4. CONCLUSION

In this work, the compressive strength of concrete produced by partially replacing Portland cement with epoxy resin was considered. A concrete mix design of 1:1.57:2.67 (Portland-cement (PC):sand:granite chippings) at water-cement ratio of 0.5, aiming for 30N/mm^3 strength was adopted. Substitution of PC with epoxy resin at 0, 10%, 20%, 30% and 40% were studied.

It was observed that the slump of the concrete became greater as the amount of epoxy resin in the mix surged. There may not be a need to use superplasticizers at a fill-in level of 20% and above. But this depends on the mix proportion, water-cement ratio, and slump required. The density of epoxy resin concrete subjected to heating for up to 100^{0}C experienced a slight reduction when compared to the unheated samples. But the inclusion of epoxy in the mix did not significantly affect the density of the concrete. All concrete produced were normal weight in nature.

Replacing of Portland cement with epoxy resin in concrete production leads to reduction in compressive strength. To achieve the desired strength improvement of epoxy-resin concrete, the mixing method for producing the concrete must be modified to achieve maximum hydration before the concrete sets. At 30% fill-in level, a rise the concrete strength was observed. All concrete studied were structural in nature except for the heated sample that was produced at 40%. The target strength of 30 N/mm^2 was only achieved by the control mix (unheated and heated) and the 10% and 30% mixes (unheated), respectively. Optimum percentage replacement of 30% was achieved from the investigation.

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