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Research Article

Feasibility Study on Using GFRP and Epoxy Resin Mix Waste Powder in Concrete to Partially Replace the Cement

Fatema Ali Hamed Muhanaa Al Shibli[1], Afnan Hilal Hamed AL Sarmi[1], Arwa Hamed Muhanna Mohammed Al Shibli[1], N. Aravind[1*], Eman Muhye Adeen Muhye Al Hatali[1], Khadija Salim Abdullah Al Balushi[2], Geetha Devi[2]

[1]Civil and Environmental Engineering Department, College of Engineering, National University of Science and Technology, Oman
[2]Mechanical & Industrial Engineering Department, College of Engineering, National University of Science and Technology, Oman
E-mail: aravind@nu.edu.om

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Abstract: Every day a huge quantity of glass fiber reinforced polymer (GFRP) and glass reinforced epoxy (GRE) waste powder is coming from the composite pipe industries in Oman. This powder is harmful to human beings and aquatic animals. Composite pipe manufacturing industries are struggling a lot with the disposal of waste GRE dust. At present, these GRE waste materials are buried under the ground without affecting the groundwater. Impervious layers are constructed to avoid seepage and protect the groundwater. Composite pipes manufacturing industries are spending huge amounts to save the environment from GRE waste disposal. In this experimental project, GRE waste is added to the concrete to partially replace cement with proportions such as 5%, 15% and 25%. Mechanical properties of concrete with and without GRE waste are investigated like compressive, split tensile strength and bending strength tests experimentally. Experimental results depict that the spilt tensile value of concrete with 5% GRE dust is 6.45% more when compared to the control specimen. Also, compressive and bending strengths of concrete with 5% GRE dust are not much affected and it is almost equal to the control specimen.

***Keywords*:** GRE waste powder, experimental investigation, strength properties, control specimen

Nomenclature

ACI	American Concrete Institute
CFRP	Carbon Fiber Reinforced Polymer
CSM	Chopped Strand Mat
GFRP	Glass Fiber Reinforced Polymer
GRE	Glass Reinforced Epoxy
LLC	Limited Liability Company
LLDPE	Linear Low-Density Polyethylene
PCB	Printed Circuit Board

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1. Introduction

GFRP and CFRP composites are commonly used to prepare pipes. GFRP composite pipes are used widely, mainly because of their excellent physical and mechanical properties like high stiffness, extraordinary strength, corrosion and heat resistance. In addition to that it has very good chemical stability. The durability of GFRP composite pipes is significant compared to steel and polyvinyl chloride (PVC) pipes. Epoxy resin and hardeners are also used for the preparation of GFRP composite pipes.

Epoxy resin is cheap, easily available in the market and it has superior properties which will be helpful for the fabrication of pipes. The viscosity of epoxy resin is higher in comparison to other thermoset plastics. This viscosity property is more helpful for the fabrication process since the impregnation of fiber can be done easily. After the completion of the fabrication of GRE pipes, curing is carried out at a temperature of 180 °C maximum. The main advantage of using epoxy resin and hardener combination is its low shrinkage properties on curing. It is more compatible with GFRP composites. Furthermore, epoxy resin has high stiffness and strength properties and hence it is an appropriate resin for the pipe fabrication process.

Owing to the excellent physical and mechanical properties of composite pipes, maintenance cost is also reduced. For the steel pipes, corrosion protection is required when it is placed below the ground level. Cathotic protection is a common method to control the corrosion of steel pipes and it needs periodic maintenance. On the other hand, during the composite pipe preparation, a huge quantity of GRE dust is coming out as a waste product. GRE is a blend of glass fibre reinforced plastic (GFRP) powder and epoxy (E) resins. The GRE dust's chemical composition consists of approximately 70% 'GR' powder and 30% 'E' resins. After the fabrication the pipes are cut and shaped into the required size with the help of grinding machine. During this process, a huge quantity of GRE powder is emerging as a waste product. Many industries in Oman are using GFRP composites and epoxy resin and they are mainly fabricating composite pipes.

Composite Pipes Industry LLC is located in Sohar. Sohar is Oman's port city and is located on the northern coast of Oman. Figure 1 shows the composite pipe before the grinding process.

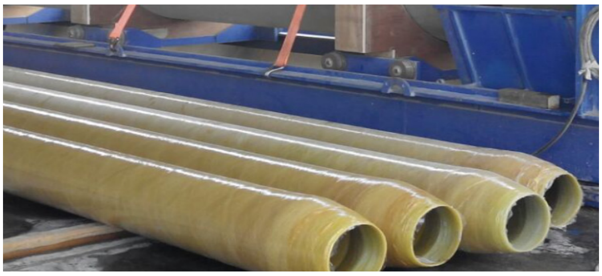


Figure 1. Composite pipes

During the grinding process huge quantity of GRE dust particles come out and this is a harmful waste material. Disposing of this waste is a huge task for the composite pipe industries. At present, these GRE waste materials are buried under the ground without affecting the groundwater. Impervious layers are constructed to avoid seepage and protect the groundwater. Composite pipe industries are spending huge money for disposing of this waste of GRE dust.

Many researchers conducted research in similar fields. Researchers used recycled GFRP waste in concrete replacing sand and studied its various properties.[1] Authors have studied the effect of using a combination of industrially processed glass fiber dust and LLDPE on mechanical, thermal and morphological properties of the remolded composites.[2] In another investigation, the powdered GFRP resin with various grain sizes was collected from the PCB waste.[3] Another study was conducted to determine the mechanical properties of hardened concrete and slump test results of fresh concrete with GFRP fibres as a partial replacement of fine aggregate.[4] Researchers have investigated the influence of CSM glass fibers on concrete rheological properties.[5] A critical review on cost analysis on recycling and reusing of GFRP composite wastes in concrete will be helpful for sustainable development.[6] Though most of the researchers used the GFRP fibre and power in concrete, the authors studied the strength properties of GFRP waste added to concrete.[7,8]

Few researchers studied experimentally the toughness and bending strength of concrete mixed with macro size GFRP composite fibres.[9,10] Researchers developed a novel GFRP based concrete and studied its porosity, and morphology properties.[11] Recently, the researchers used the GFRP waste powder in the preparation of concrete and geopolymer mortar with ground granulated blast furnace slag (GGBS). In addition to that they studied the microstructures and properties of concrete with GFRP waste.[12]

In the GRE pipe manufacturing process, E-type high-strength fibreglass and amine cured epoxy resin combinations are used as a base and main ingredients. The inner portion of the pipe is prepared with C-glass fibre mixed with a more quantity resin layer. The reason for using C-glass fibre has excellent chemical resistant properties and hence it is used in the inner line of the GRE pipes. Likewise, epoxy resin has resistance to chemicals, water, hydrocarbons, etc. Based on the material properties description provided by the manufacturer, the design temperature and pressure for the GRE pipe are 110 °C and 120 bar respectively. Also, the coefficient of linear thermal expansion along the axial direction for the GRE pipe is 18×10^{-6}/°C tested based on ASTM D696.[13]

While numerous researchers have explored using glass fibres and powders in concrete and other composites, our study stands out as we focus on adding GRE dust particles to concrete. This unique approach allows us to analyze the strength properties of concrete with GRE dust, providing valuable insights into a novel application of this waste material.

The main objectives of the present study consist of the collection of GRE dust from the industry, determination of mix proportion using ACI code, conducting the workability test, casting, conducting compressive, spilt tensile strength test and bending strength tests on cubes, cylinders and reinforced concrete beams with and without GFRP dust after curing process respectively. Finally, the test results are compared between the normal concrete and concrete with GFRP dust. The novelty of the present study is to use of GRE waste powder in concrete to partially replace the cement.

2. Materials

2.1 *Constituents of concrete*

Ordinary portland cement (OPC) was used to prepare various concrete specimens like cubes, cylinders and beams.[14] Manufactured sand (M-sand) with a size of 5 mm (maximum) was used as fine aggregate. A sieve analysis test was conducted to find the fineness modules of M-sand. A maximum of 20 mm coarse aggregates were used for concrete as filler. For casting and curing, water is used which is fit for drinking. Mix design for the C30 concrete grade is calculated according to ACI code.[15,16] According to the mix design, a mix proportion of 1 : 2.15 : 2.53 and water/cement proportion of 0.5 was used for casting work.

Figure 2. GRE dust

2.2 *GRE dust*

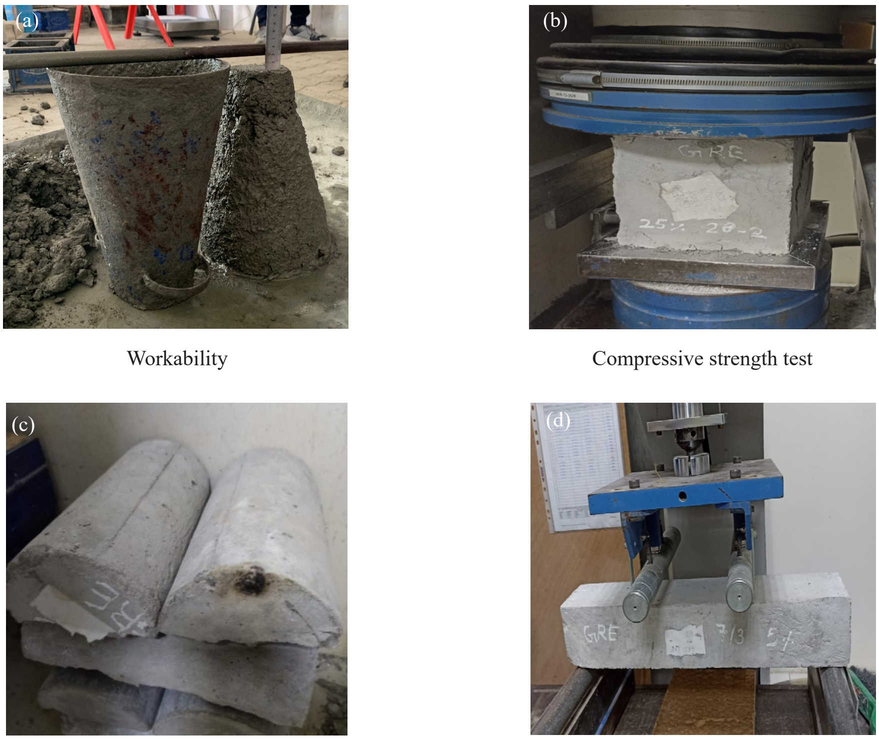
GRE dust was collected from the Composite Pipes Industry LLC, Sohar, Oman as shown in Figure 2. It is freely available in very fine powder forms and hence this is partially replaced with cement. GRE dust powders are mixed with concrete in percentages of 5%, 10%, and 15% as partial replacement of cement. Every day a huge quantity of GRE dust powder is coming out from the composite pipe fabrication industries. This powder is harmful to human beings and aquatic animals. Composite pipe manufacturing industries are struggling a lot with the disposal of waste GRE dust. Hence, in the present study, a feasibility experimental study is conducted to use the harmful waste material effectively. This GRE waste powder is white in color.

3. Experimental methodology

3.1 *Casting and curing*

In total, 12 cubes, 8 cylinders and 4 beams were cast for the comparative analysis of concrete with and without GRE dust. For the casting work, the size of molds used for the cube of size 150 mm, for the beam of size 100 mm × 100 mm × 500 mm, for the cylinders of diameter and length are 150 mm and 300 mm respectively.

After the casting, all the cast specimens are kept in water for curing. After casting and curing for 28 days, 12 cubes, 8 cylinders and 4 beams are tested for compressive, split tensile and bending strengths respectively. The beam size is large hence, only one sample per each mix is used for casting. But, 3 cubes and 2 cylinders were cast for each mix to determine the average strength.



Workability

Compressive strength test

Cylinder specimen after the test

Bending strength test

Figure 3. Experimental test

3.2 *Workability test*

The workability of concrete under fresh conditions is measured by conducting the slump test. It was carried out for all four mixes such as normal concrete, concrete with 5, 15 and 25% of GRE dust as partial cement replacement. Figure 3a shows the slump test conducted at the laboratory.

3.3 *Compressive strength test*

Before conducting the compressive strength tests on hardening concrete, the weight of the cubes is observed and the mass density of the concrete. For the reinforced concrete structures design, characteristic compressive strength of concrete is required. Compressive load is applied gradually on the cube specimens using a 300-Ton compressive strength testing machine. Figure 3b shows the compression applied on the cube with 25% GRE dust.

3.4 *Split tensile strength test*

The split tensile strength test is a common lab test for the determination of the concrete's tensile strength. A 150 mm diameter and 300 mm length cylindrical specimen is placed horizontally, and a force is applied to its surface. Figure 3c shows the cylinder specimen after the failure load.

3.5 *Bending strength test*

The bending capacity of a beam gives the maximum amount of bending stress that a beam can carry before failure. In the present study, a simply supported beam of span 450 mm and two-point loads were applied with a spacing of 150 mm according to Figure 3d.

4. Results and discussions

4.1 *Sieve analysis and mix proportion*

Texture and size of the sand and coarse aggregates are determined using sieve analysis. Table 1 depicts the particle density and fineness modulus of sand and coarse aggregates.

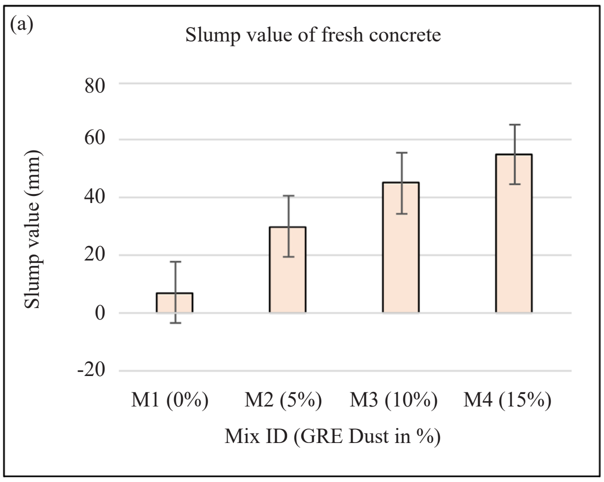
Table 1. Particle density and fineness modulus

Type of aggregate	Particle density (g/cm^3)	Fineness modulus (%/100)
Sand	2.7	4.5
Coarse	2.6	4.8

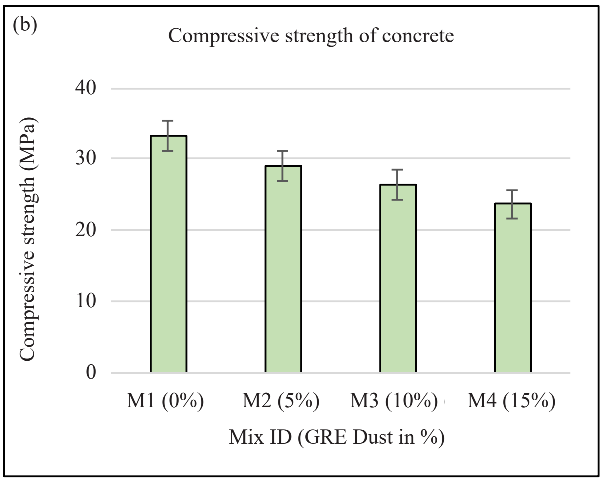
Concrete constituents like cement, sand and coarse aggregates are mixed at the ratio of 1 : 2.15 : 2.53. This proportion corresponds to C30-grade concrete and is calculated as per ACI standards. In addition to that, the water/binder adopted for the mixing is 0.5.

4.2 *Workability test results*

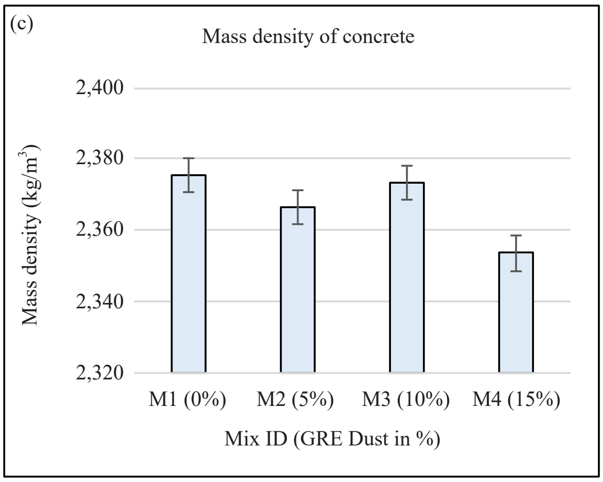
Table 2 depicts the workability test results for the concrete in fresh conditions with and without GRE dust. Figure 4a depicts the bar chart of slump values of mixes with 0%, 5%, 15% and 25% GRE dust. The workability laboratory experiment results portray that, the concrete with 15% GRE dust gives the ultimate slump value of 55 mm. The slump type for the controlled fresh concrete and others with 5%, 15% and 25% GRE dust is the 'true' type. None of the mixes failed by shear or collapse-type slump. Low workability is observed for the controlled fresh concrete with a value of 7 mm which is the lowest value among all the four mixes.



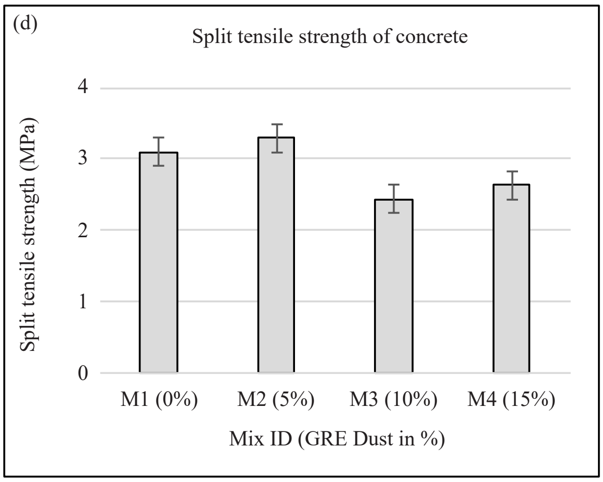
Slump test results



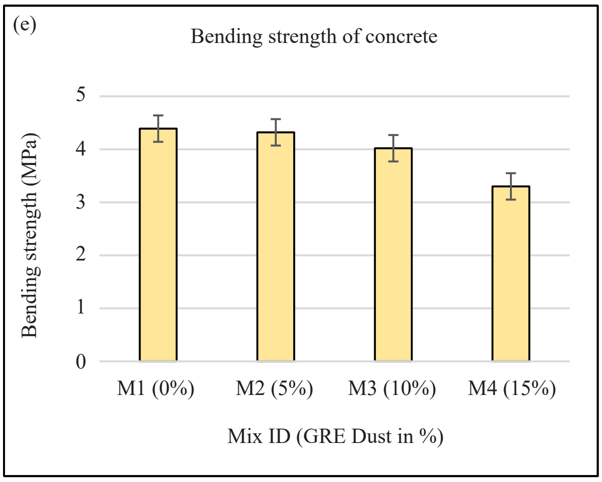
Compressive strength test results



Mass density of mixes



Split tensile strength test results



Bending strength test results

Figure 4. Experimental test results

Table 2. Workability test results

Mix No.	GRE dust (%)	Slump value (mm)	Type of slump
M1	0	7	True
M2	5	30	True
M3	10	45	True
M4	15	55	True

4.3 *Compressive strength and unit weight*

This is one of the essential properties of concrete suitable for fixing the concrete grade. Before conducting this test, the weight of each specimen is noted to determine the mass density of concrete with and without GRE dust. For this experiment, the cube specimens are subjected to a load of 6.80 kN/s. Table 3 portrays the average failure load and corresponding strength due to compression. In this study, C30-grade concrete is designed and cast. Experimental results show that the average strength of a normal mix is 33.30 MPa which meets the required compressive strength. Figure 4b depicts the bar chart of cube specimens with various percentages of GRE dust versus compressive strengths.

The strength due to compression on concrete with 5%, 15% and 25% GRE dust is 12.64%, 20.57% and 28.77% less than that of concrete without GRE dust. Based on the experimental values, the addition of GRE is inversely proportional to the strength.

Table 3. Compressive strength test results

Mix No.	GRE dust	Average weight of cube (kg)	Mass density (kg/m^3)	Average failure load (kN)	Average compressive strength (MPa)
M1	0%	8.017	2,375.41	749.21	33.30
M2	5%	7.987	2,366.62	654.45	29.09
M3	10%	8.010	2,373.43	595.10	26.45
M4	15%	7.944	2,353.68	533.80	23.72

4.4 *Split tensile strength test results*

Table 4 portrays the tensile strength (split) of concrete cylinders. Figure 4c depicts that the mass density of concrete with and without GRE dust is almost the same. For this experiment, load is applied at 0.50 MPa/s. Figure 4d depicts the bar chart of the strength results of various mixes. The tensile strength (split) of concrete with 5% GRE dust is 6.45% higher than that of the control specimen. However, spilt tensile strength of concrete with 15% and 25% GRE dust is less than that of normal concrete without any GRE dust.

4.5 *Bending strength test results*

Table 5 shows the bending strength of beams for all four mixes with and without GRE dust particles. The bending strength of concrete with 5%, 10% and 15% GRE dust is inferior of the controlled specimen. However, the bending value of the beam with 5% GRE dust is 1.59% less than that of the controlled specimen, which means their values are almost the same.

For the bending strength experiment, the beam specimens are subjected to a load of 0.10 kN/s. Figure 4e depicts the bending strength test values bar chart for various mixes.

Table 4. Split tensile strength test results

Mix No.	GRE dust	Average failure load (kN)	Average split tensile strength (MPa)
M1	0%	218.79	3.10
M2	5%	232.92	3.30
M3	10%	172.63	2.44
M4	15%	186.44	2.64

Table 5. Bending strength test results

Mix No.	GRE dust	Failure load (kN)	Bending strength (MPa)
M1	0%	9.757	4.39
M2	5%	9.605	4.32
M3	10%	8.942	4.02
M4	15%	7.325	3.30

5. X-ray diffraction analysis

The X-ray diffraction (XRD) analysis was conducted to study the composition and crystalline behavior of cement, GRE dust with various mix proportions. The X-ray diffraction analysis was carried out at the in-house chemical engineering laboratory in the College of Engineering, National University as shown in Figure 5. In total 5 samples are tested for the XRD analysis as shown in Table 6. For the analysis, the length of each specimen is 10 mm and the temperature of 25 °C during the measurement. From the analysis, the main graphics between the °2θ and corresponding counts are observed. Peak values of all the samples are observed from the analysis and included in Table 6.

Table 6. XRD analysis test

Mix ID	GRE dust (%)	Cement (%)	Peak count	Corresponding position (°2θ)
1	0	100	650.61	29.4077
2	5	95	594.61	29.3669
3	10	90	312.79	29.3209
4	15	85	567.39	29.3905
5	100	0	-	-

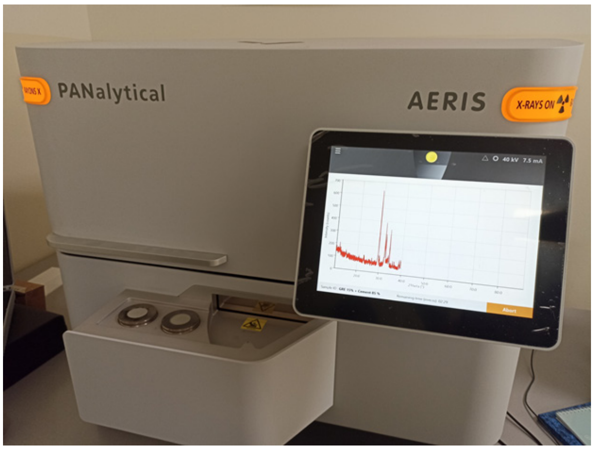
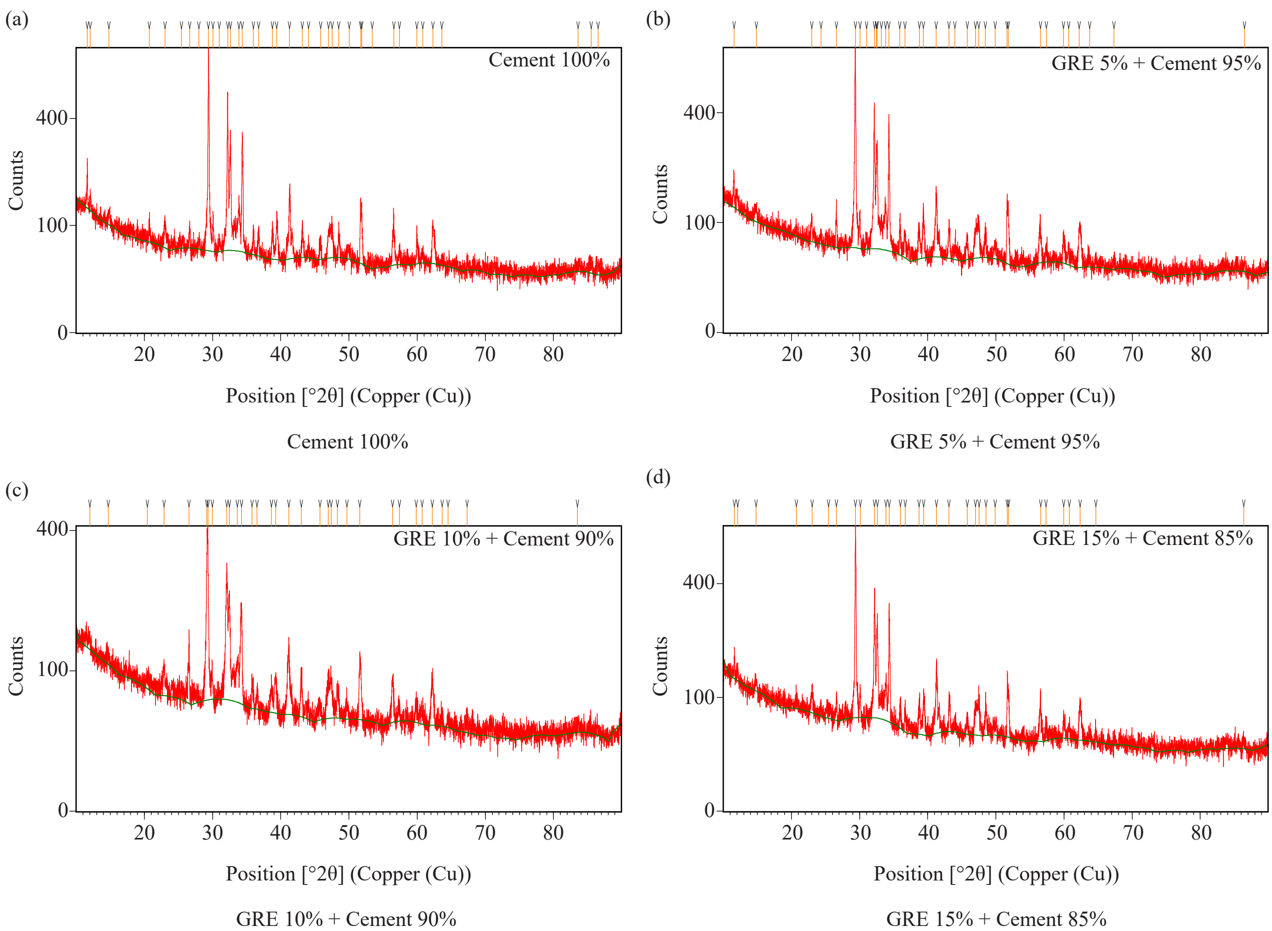
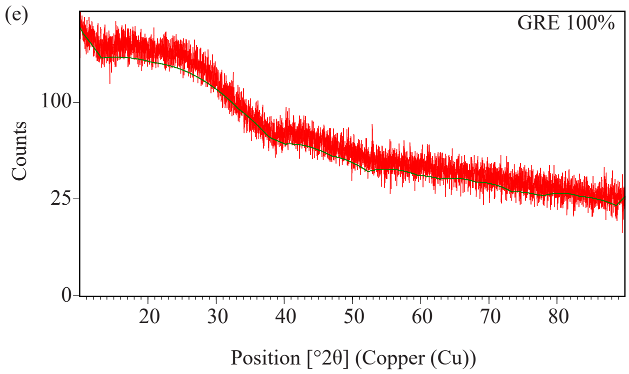


Figure 5. XRD test equipment

From the XRD analysis graph, it is noted that the thinner peak corresponds to a 100% cement sample. Also, it is noted that the width of the peak is increasing in trend corresponding to samples with increasing percentage of GRE dust. Figures 6a to d depict that sample 1 with 100% cement is a crystalline structure and the samples with GRE dust with 5 to 15% a slightly deficient in crystallinity respectively. Figure 6b to d shows that the mixes are a mixture of crystalline and amorphous components and Figure 6e is a pure amorphous component.





GRE dust (100%)

Figure 6. XRD analysis

6. Conclusions

The conclusions are drawn below as per the experimental analysis and corresponding results. The slump/fall values of concrete in fresh condition are proportionate with the quantity of GRE dust mixed. Also, the type of slump for all the mixes is 'true' and none of the mixes are collapsed or failed by shear. Pertaining to the experiments, the strength of the cube specimens subjected to the compression is diminishing in trend when GRE dust particles are mixed to the concrete. However, the concrete with 5% GRE dust is almost equal to the 30 MPa. The authors recommended adding a chemical admixture superplasticizer to increase the strength in compression. The strength (spilt tensile) of concrete with 5% GRE dust is 6.45% more when compared to normal concrete. However, the strength (split tensile) of concrete with 15% and 25% GRE dust is less than that of the control specimen. The bending strength of the concrete beam is inversely proportional to the concrete with GRE dust. However, the bending strength of concrete with 5% GRE dust is almost similar to that normal concrete. X-ray diffraction analysis results revealed that the cement and GRE dust are crystalline and amorphous in nature.

Acknowledgement

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Conflict of interest

The authors declare that they have no conflicts of interest.

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