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Optimization of concrete produced from industrial waste and fibre using regresion model

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ABSTRACT

This research examined the potential for reusing glass fiber, fly-ash, and quarry dust, in concrete production through partial substitution of traditional cement and sand. The study employed an experimental mix design to ascertain the compressive strength of concrete when these waste materials are incorporated. Various tests, including compressive strength, slump, and air void tests, were conducted on concrete cube samples with varying percentages of waste material substitutions. The cube samples were designed with specific proportions: fly-ash replaced cement at increments of 10%, 20%, and 30%, while glass fibers were added as an admixture at 1%, 2%, and 3%. Similarly, quarry dust replaced sand at 10%, 20%, and 30%, with glass fibers added at the same percentages. Additional cube samples were prepared with quarry dust and fly ash partially replacing sand and cement at 5%, 10%, and 15%, with glass fibers added at 1%, 2%, and 3%. These samples were subjected to a curing process in water for durations of 7, 14, 21, and 28 days. A linear regression model was developed based on forty compressive strength test results, positioning compressive strength as the dependent variable and the volume of glass fibers, quarry dust and fly ash as independent variables. A model of the form: CS = 0.216Vgf + 0.068Vqd + 0.979Vfa + 26.078 was developed where CS is the compressive strength, while Vgf, Vqd and Vfa represent volume of glass fibers, quarry dust and fly ash with their coefficients respectively. The model's findings indicate that the industrial waste that significantly enhances the compressive strength of the concrete is fly ash, followed by glass fibers, while quarry dust has minimal influence. The optimal strength achieved was 24.89 N/mm2 at 28 days when fly-ash, quarry dust, and glass fibers were combined.

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1. INTRODUCTION

1.1 Background of the Study

One of the most important construction materials for development of infrastructural facilities is concrete [1]. Researchers have proven that waste material can replace cement or aggregate in concrete [2]. There are two ways in which the environmental advantages of using waste materials to replace cement can be investigated. One is by removing a certain percentage from the cement in the concrete and the other is using waste materials that are not suitable in concrete.

Concrete is a combination of cement, fine aggregates and coarse aggregates, water and additives. There are several weaknesses noticed in the traditional concrete, these weaknesses include low ductility, low energy absorption, low tensile strength, low crack resistance and shrinkage cracking [3]. Different types of fibers have been mixed with concrete to overcome these defects [4]. This type of concrete is named Fiber Reinforced Concrete (FRC) is the name given to this type of concrete which is concrete produced from the combination of ordinary Portland cement, sand and coarse aggregates, incorporated with fibers [5]. The mechanical properties of the concrete are improved with the incorporation of fibers, in order to reduce costs the fiber can be used in a powdered form for partial replacement of cement, the release of hydration heat and the shrinkage phenomena associated with the use of this binder [6], as reinforcement for polymeric tubes used to confine recycled aggregate in concrete [7], as link slabs in engineered cementitious composite materials, in concrete bridge deck and it is used for repairing ordinary Portland based concrete.

This study is aimed at evaluating the compressive strength of concrete produced by substituting cement and sand with fly-ash and quarry dust with glass fibers as admixture and determining the optimal mix.

Concrete which is a widely used material in construction and play a very important role in providing safe environment to the global population. Concrete is the most used resource alongside water. Good concrete has outstanding durability and mechanical properties, and is an exceptional engineering material. With cement as the binding medium for concrete, the world produces over 4 billion tons of cement for the last five years, but that number is expected to rise enormously by 2050 [8]. Due to this huge production of cement for concrete, a plan to limit its impact on the depletion of natural resource and the surrounding environment is vital. Cement on its own causes anthropogenic global emissions, it is also responsible for almost 5-7% of Carbon (iv) oxide (CO2) and 3% of global Green-house gases emissions [9].

In order to strike a balance between the industry growth and the structural limits of the planet and to ensure the competitiveness of the construction material, it is essential to develop plans to reduce concrete impact on the environment which brought about this research.

The aim of this research is to determine the optimal mix of concrete produced from industrial waste and fiber using regression model. The specific objectives are to:

a) develop an experimental mix of concrete produced from cement and sand replacement with fly ash, quarry dust with glass fibers as admixture at varied proportions;
b) produce concrete with fly ash and quarry dust partially replacing cement and sand with glass fiber as admixture at varied mixes from (a);
c) evaluate the strength characteristics of concrete from (b), and
d) determine the optimal mix using regression model.

Millions of wastes are generated around the world annually and are dumped all over the places, contaminating the soil, affecting the ecosystem and the environment. When these wastes accumulate in the suburbs it affects the environment negatively and disposing these wastes in an unhealthy manner into sewage, landfills and open dumps are very dangerous for the environment especially the contamination of ground water, if 20% of the waste from each waste sector is reused every day, it could lead to a massive reduction in landfills and dumpsite congestion and relevant unhealthy waste disposal activities [10]. With the rising cost of cement in the construction industry, using waste material in concrete production as cement replacement will help in eliminating waste and reducing concrete production cost to tune of millions in a year. Due to the rate in which the green concrete industry is expanding, it is important to evaluate waste incorporated concrete from construction in order to evaluate the effectiveness of the concrete which is the base of this study.

This research evaluated the compressive strength of concrete produced from varied mixes of industrial waste and fibers. This research focused on using fly ash and quarry dust as substitutes for cement and sand at specified proportions and percentages with glass fibers added using 1%, 2% and 3% as admixtures in concrete production. Compressive strength and workability tests were performed on the concrete cubes produced. A linear regression model was then developed to describe the relationship between the compressive strength and the replacement level of fly-ash for cement, quarry-dust for sand and glass fibers as admixtures.

2. Literature review

2.1 Cement as a Construction Material

Cement is any substance which binds together other materials by a combining a series of chemical processes known collectively as setting. Cement is a powdered substance made of calcined lime and also having clay as main ingredients. Clay used provides silica, alumina, iron oxide, and calcium oxide are basically provided by the calcined lime. Cement is an important constituent in concrete and mortar, because cement is the main component of both of these building materials, cement is a very essential construction material. It is used in the construction of many structures including buildings, roads, bridges, runways and harbours.

However, due to the production of cement a significant amount of anthropogenic carbon dioxide is emissioned [9] However, the cement industry produce different types and amount of air pollution and these depend on several parameters, such as the fuels and the raw materials used and the process used in the industry [11].

In the modern age cement is an important construction material for survival. Due to the importance of cement to human, production of cement is compulsory. At the same time it is vital to control the pollutions caused by the cement industry. The various processes through which the pollution could be controlled are carbon capture and storage, adsorption of CO_2 into advanced sorbents, zeolites, and use of metal organic frameworks.

2.2 Properties of Concrete containing Industrial Wastes

Industrial wastes are used as replacement materials for cement in concrete. These wastes include glass, silica fume, fly ash, agricultural waste, ceramic and sanitary tiles with clay bricks

Silica fume is a product of electrostatic capturing and tranquilising of silica dust with gasses discharged from electric arcs or alloys in the production process of silicon metal, particularly ferrosilicon alloys. This material has more than 80% non-crystalline silica with a diameter between 0.01 and 0.3 microns, which is about 50 to 100 times smaller than cement particles [1]. It is a 'super pozzolan' that can improve Portland cement production properties. It modifies the physical characteristics of early cement paste and the microstructural characteristics of cement paste after hardening [12]. Studies on high performance concrete have shown that increasing the super-plasticizer from 5 to 20% and decreasing the water-cement ratio from 0.31 to 0.26 caused an increase in compressive strength from 86 to 97 Mpa [13].

Researchers have shown that glass particle size has an obvious effect on concrete performance. Smaller particles increase activity with lime, improve compressive strength and reduce shrinkage. In high performance concrete, if glass powder is shattered into micro scale, it establishes useful reaction with cement over time and its formation of calcium silicate hydrate (C-S-H) is very useful for the structure and characteristics of high-performance concrete [14].

From agricultural waste, rice husk ash is the most applicable rice husk ash has high pozzolanic potential. It also improves resistance to chloride attack, compressive strength and other mechanical properties [15]. Adding a super plasticiser can also increase slump and decrease viscosity. Using rice husk ash can reduce the filling ability of concrete; however, paste viscosity and segregation rose sharply. By combining rice husk ash and fly ash the self-compacting and compressive strength properties of concrete improved [16]. Finally, studies have showed that in countries with limited production, rice husk ash can be a valuable additive in concrete products such as high-strength concrete and reconstructive mortars.

In power plants that are fueled by coal, there are spherical particles in the gas that come from burning coal with a diameter of 0.1 to 0.15 mm; the particles are made up of about 85% of silicon, aluminium, iron, magnesium and calcium. These particles are called fly-ashes. According to ASTM C618, fly ash has two classes, Class F and Class C. The main difference between the two is on the levels of calcium, aluminum, silicon and iron content in the ash. Generally, Class F fly ash with good pozzolanic activities cause good mechanical properties, durability and low chloride permeability. Chung-Ho showed that in fly ash concrete, setting time and air percentage increased with enhancement of fly ash dose, however, increasing fly ash in concrete caused higher shrinkage due to drying at different ages [17].

A tile is a piece of artificial stone with thickness of a few millimeters and a glassy, soft and smooth surface on one side. Ceramic is a non-metallic and non-organic material. It is classified in two categories of crystalline and non-crystalline. Tile and ceramic waste is created during the transfer process, during or after burning, due to human error, manufacturing error or use of inappropriate material and much of it is due to the destruction of buildings [1]. Many studies have been done to dump this waste in concrete. The results of experiments showed that it would be feasible to use tile waste in concrete as pozzolan or aggregate [18,19]. Using white ceramic aggregates as fine aggregate and substituted with ratios of 10% to 50%, the quality of concrete improved [20]. Moreover, if porcelain sanitary waste is used as coarse aggregate in concrete at a rate of 3% to 9%, its resistance is more than that of concrete without additives at a rate of 2% to 8% [21]. Thus, the replacement of natural aggregates with waste aggregates can increase water penetration resistance [22].

2.3 Properties of Concrete containing Industrial Fibers

Concrete containing fibers for the purpose of improving the concrete inherent properties is called fiber reinforced concrete. However, if the industrial fibers are recyclable, it is referred to as recyclable fibers reinforced concrete (RFRC). The presence of fibers improves the concrete performances, by increasing toughness, ductility and resistance to impact while reducing its weight and density, and, therefore, by improving the high strength-to-weight ratio [23, 4 & 3]. Particularly, fibers control cracking due to both plastic and drying shrinkage. The presence of fibers in concrete does not affect the occurrence of cracks, but succeeds in delaying their propagation [23]. The addition of fibers also reduces the permeability of concrete thus positively affecting its durability [16] and reducing bleeding phenomena. Depending on fibers shape and dimensions, it is also possible to obtain improved freeze-thaw resistance [24]. Finally, enhancement in fire resistance has been observed [25]. Major drawbacks of fibers addition in the concrete formulation are the possibility of reducing workability [26]. and the higher costs associated either to fibers, if not deriving from waste or scrap recovery, or to super plasticizers requirements. Fibers can be of natural (animal, mineral and cellulose/lignocellulose), or synthetic origin (organic and inorganic) [27]. Among these, steel, glass, natural cellulose, carbon, nylon, polypropylene are the most used [3].

2.4 Present Status of Research

Chung-Ho [17] showed that in fly-ash concrete, setting time and air percentage increased with increase in fly-ash dose. He also proved that concrete mixtures containing fly ash with low loss of ignition had higher mechanical properties compared to concrete mixtures containing fly ash with high loss of ignition.

Chaitanya et al. [28] performed an investigation into glass fiber concrete using M20 grade concrete and glass fiber. The glass fibers were added at 0.5%, 1.0%, 2.0% and 3.0%. The result of the compressive strength of concrete for 28 days was 27,06 N/mm2, 28.46 N/mm2, 26.88 N/mm2and 26.108 N/mm2 for fiber content of 0.5%, 1.0%, 2.0% and 3.0% respectively. The percentage increment compared to the normal concrete (without fiber) was 35.3%, 42.3%, 34.9% and 30.54% for the respective fiber content.

Ilangovana [29] performed a study to show the feasibility of complete 100% replacement of river sand in concrete with quarry dust. The result showed that concrete with its sand made up of quarry dust showed 10% increase in compressive strength, flexural strength and durability than the Natural Sad Concrete

Burak Felekoglu [30] identified that the integration of equal amount of quarry waste and the equal amount of cement content generally reduced the super plasticizer requirement and improved the 28 days compressive strength of Self Compacting Concrete.

Sebaibi [31] performed the assessment of properties of concrete containing glass waste fiber and polyester powder derived from thermoset composite. The result showed that the compressive, flexural strength and slump showed a 20% increased than the normal concrete.

Murahari and Rao [32] performed a study on the effect of polypropylene fibres on the strength properties of fly ash based. Fibre volume fraction of 0.15%, 0.2%, 0.25% and 0.3% was used in fly ash concrete with CLASS C fly ashof specific gravity of 1.96 obtained from NLC. Fly ash content was varied as 30%, 40% and 50%, while the coarse aggregate used was 12mm (40%), and 20mm (60%) with specific gravity of 2.7. The compressive strength of concrete mixes made with and without fly ash and polypropylene fiber was determined at 28days as well as 56days. They concluded that the compressive strength of concrete increases gradually by the addition of polypropylene fibre from 0.15% to 0.3%.

Balamurugan and Perumal [33] discussed the use of quarry dust as a sand replacement material for concrete production which showed a maximum increase in compressive strength (19.18%), tensile strength (21.43%) and flexural strength (17.8%) at 50% sand replacement by quarry dust. This result gives clear view that quarry dust can be utilized in concrete mixtures as a good substitute for natural river sad at 50% replacement. The need in replacing the natural sand river in concrete’s ingredients with additional strength than control concrete can be solved by the utilizing of quarry dust obviously.

2. RESEARCH METHOD

The materials used for this research are potable Water, Fly ash, Glass Fibers, Quarry dust, Sand, Cement and Crushed Granite. The concrete grade used is grade 20.

The clean water conforming to BS1348-2(1980) was used to mix the materials and cure the concrete samples. Sand was used as fine aggregate. Basic test was conducted on the sand in accordance with BS 1377 (Part 1) 1990. This includes Sieve Analysis Test, specific gravity test.

The type of cement used for this research was Ordinary Portland Cement, it was used for this research as a binder and it was sourced from Akure. Crushed granite (graded size of 19mm) was used as the coarse aggregates. The materials were dried appropriately and free of harmful and damaging materials such as chloride contaminants, clays and silt content. The materials were gotten from Johnsons Nigeria Limited here in Akure, Ondo State, Nigeria. The glass fiber used for this research was alkali resistant ACS19PH901X, manucfactured by Nippon Electrical Company Limited in collaboration with Kanebo Limited. The glass fibers are alkali resistant to avoid bleeding reaction with the cement. Fly ash is a pozzolanic material that is also known as pulverized fuel ash (PFA). The Fly ash used for this research is Class F and it was obtained from the thermal coal station at Oji River, Enugu state Nigeria. The quarry dust used was obtained from Stone Works Quarry in Akure. The chemical and physical properties of the quarry dust was performed experimentally.

Laboratory tests

The laboratory tests conducted were sieve analysis, slump, chemical composition, air void, specific gravity and compressive strength determination.

i. Slump test

The concrete slump test was used to measure the workability and consistency of the freshly mixed concrete before it sets. This test was conducted in accordance to BS EN 12350-2.

ii. Setting time test

In order to determine the effects of the admixtures added on the hydration of the cement used in mixing the fresh concrete the setting time test was carried out using the Vicat's apparatus according to BS ISO 1920-14:2019.

iii. Particle size distribution

This presents the relative portions of different sizes of particles of soil in accordance to BS 1377-2.

iv. Specific gravity

The Specific gravity is defined as the ratio of the weight of sample to the weight of equal volume of water. The method of obtaining the specific gravity is ASTM C 128. The specific gravity of an aggregate shows important data about its standards and characteristics.

v. Determination of air void in concrete

The pressure method as described in (BS 1881., 1993) was used to perform this test. The freshly mixed concrete was poured in the pressure air meter and tamped down in 3 layers. 50 blows was delivered to each layer and the apparatus was tightly clamped. The calibrated tube was filled with water up to the zero mark. The bicycle pump was used to apply air pressure into the concrete and a pressure gauge was used to measure it.

vi. Compressive Strength Test

The compressive strength of the concrete cubes were tested in accordance with (BS.1881-116, 1983) after 7, 14, 21 and 28 days of curing. One hundred and sixty (160) pieces of 150 x 150 x 150mm cubes made with fly-ash, quarry dust, and glass fibers in varied portion per volume of concrete were tested and the result for each cube were recorded. The test was carried out using the Automatic Universal Testing Machine.

3.3 Mixing and Casting of Concrete

For the mixing of ordinary concrete, cement and sand were weighed and thoroughly mixed after which the crushed granite was added and mixed. Adequate amount of water was poured to the mixture and mixed thoroughly in order to get a consistent concrete. The freshly mixed concrete was filled in the casts. Caution was taken to ensure the concrete was perfectly compacted. After casting and curing for 24 hours all the test samples were demoulded. For concrete with replacements, cement and sand was initially mixed together, followed by addition of fibers at 1%, 2% and 3%. The addition of fibers was performed in different proportion by percentage volume of concrete. The fiber was gently added into the mix to avoid balling. Coarse aggregates and water was added to the mixture after it has been thoroughly mixed, after adding the coarse aggregates the mixture was carefully mixed to steer clear of concrete bleeding. The same process got repeated but with cement replacement by volume with 10%, 20% and 30% by volume of fly ash and sand replacement by volume with 10%, 20% and 30% by volume of quarry dust. The combined composition of cement and sand replacement were made with fly ash at 5%, 10% and 15% and quarry dust at 5%, 10% and 15% while incorporating the 1%, 2% and 3% glass fibers as admixture. Fourty (40) cubes were tested after curing for 7 days, 14 days, 21days and 28 days. The aggregates were added dry in order not to influence the mix ratio and study performance. The sand that was used in the concrete was oven dried properly before the sieve analysis test was carried out. The slump test, setting time and compressive strength test were performed to investigate the properties of concrete. Table1 shows the experimental mix proportion details.

Table 1: Experimental concrete mix set-up

S/N	Concrete mix designations	Cement (%)	Sand (%)	Granite (%)	Fly ash (%)	Quarry dust(%)	Glass Fibers (%)
1	M01	100	100	100	-	-	0
	M02	100	100	100	-	-	1
	MO3	100	100	100	-	-	2
	MO4	100	100	100	-	-	3
2	MF0	90	100	100	10	-	0
	MF1	90	100	100	10	-	1
	MF2	90	100	100	10	-	2
	MF3	90	100	100	10	-	3
3	2MF0	80	100	100	20	-	0
	2MF1	80	100	100	20	-	1
	2MF2	80	100	100	20	-	2
	2MF3	80	100	100	20	-	3
4	3MF0	70	100	100	30	-	0
	3MF1	70	100	100	30	-	1
	3MF2	70	100	100	30	-	2
	3MF3	70	100	100	30	-	3
5	MQ0	100	90	100	-	10	0
	MQ1	100	90	100	-	10	1

	MQ2	100	90	100	-	10	2
	MQ3	100	90	100	-	10	3
6	2MQ0	100	80	100	-	20	0
	2MQ1	100	80	100	-	20	1
	2MQ2	100	80	100	-	20	2
	2MQ3	100	80	100	-	20	3
7	3MQ0	100	70	100	-	30	0
	3MQ1	100	70	100	-	30	1
	3MQ2	100	70	100	-	30	2
	3MQ3	100	70	100	-	30	3
8	MQF0	95	95	100	5	5	0
	MQF1	95	95	100	5	5	1
	MQF2	95	95	100	5	5	2
	MQF3	95	95	100	5	5	3
9	2MFQ0	90	90	100	10	10	0
	2MFQ1	90	90	100	10	10	1
	2MFQ2	90	90	100	10	10	2
	2MFQ3	90	90	100	10	10	3
10	3MFQ0	85	85	100	15	15	0
	3MFQ1	85	85	100	15	15	1
	3MFQ2	85	85	100	15	15	2
	3MFQ3	85	85	100	15	15	3

A total of 160 experimental samples was cast and tested in the laboratory.
Where:

M01 is mix specimen containing conventional concrete.
M02 is mix specimen containing conventional concrete with 1% glass fibers.
M03 is mix specimen containing conventional concrete with 2% glass fibers.
M04 is mix specimen containing conventional concrete with 3% glass fibers.
MF0 is mix specimen containing 90% cement, 10% fly ash, no quarry dust, no glass fibers, fine aggregates, coarse aggregate and water.
MF1 is mix specimen containing 90% cement, 10% flyash, no quarry dust, 1% glass fibers, fine aggregates, coarse aggregate and water
MF2 is mix specimen containing 90% cement, 10% fly ash, no quarry dust, 2% glass fibers, fine aggregates, coarse aggregate and water
MF3 is mix specimen containing 90% cement, 10% fly ash, no quarry dust, 3% glass fibers, fine aggregates, coarse aggregate and water
2MF0 is mix specimen containing 80% cement, 20% fly ash, no quarry dust, no glass fibers, fine aggregates, coarse aggregate and water
2MF1 is mix specimen containing 80% cement, 20% fly ash, no quarry dust, 1% glass fibers, fine aggregates, coarse aggregate and water
2MF2 is mix specimen containing 80% cement, 20% fly ash, no quarry dust, 2% glass fibers, fine aggregates, coarse aggregate and water
2MF3 is mix specimen containing 80% cement, 20% fly ash, no quarry dust, 3% glass fibers, fine aggregates, coarse aggregate and water

Linear Regression Model

A regression model is defined as a type of predictive modelling technique that examines the correlation between a dependent (target) and independent variable (predictor). This technique is used for forecasting, time series modelling and finding the fundamental effect relationship between variables. By using regression modelling, the best fit equation was obtained between compressive strength and volume of fibers, quarry dust and fly ash as presented in Equation 1.

$$CS = \beta_0 + \beta_1 V_{gf} + \beta_2 V_{qd} + \beta_3 V_{fa} + c \quad (1)$$

Where:

β_0	is	Constant
CS	is	Compressive Strength
V_{gf}	is	Volume of glass fibers
Vqd	is	Volume of quarry dust
Vfa	is	Volume of fly-ash
C	is	Intercept
$\beta_0, \beta_1, \beta_2, \beta_3$	are	Coefficient values of volume of glass fibers, quarry dust and fly-ash respectively.

The regression model was developed using the regression mathematical function in Excel worksheet, 2016.

4. RESULTS AND DISCUSSIONS

4.1 Chemical analysis

Table 2 presents the chemical composition of three construction materials: Cement, Fly-Ash, and Quarry Dust. The elements are measured in percentages and include Silica (SiO_2), Alumina (Al_2O_3), Iron (Fe_2O_3), Calcium oxide (CaO), Magnesium oxide (MgO), Sodium oxide (Na_2O), SO3, Potassium oxide (K_2O), Titanium oxide (TiO_2), and Loss on Ignition (LOI).

Table 2: Chemical elements of research materials

Chemical elements	Cement	Fly-Ash	Quarry Dust
Silica (SiO_2)	19.92	54.13	62.48
Alumina (Al_2O_3)	6.54	30.01	18.72
Iron (Fe_2O_3)	2.09	9.14	6.54
Calcium oxide (CaO)	64.7	-	4.83
Magnesium oxide (MgO)	1.84	2.94	2.56
Sodium oxide (Na_2O)	0.28	0.95	-
SO_3	3.34	-	
Potassium oxide (K_2O)	0.56	1.53	3.18
Titanium oxide (TiO_2)		-	1.21
Loss on Ignition (LOI)	0.73	1.3	0.48

Some key observations from the Table 4.1 include:

a. High Silica Content in Fly-Ash and Quarry Dust: Silica is the major element in Fly-Ash (54.13%) and Quarry Dust (62.48%), compared to Cement (19.92%). This high silica content could make Fly-Ash and Quarry Dust suitable for high-strength concrete applications.

b. Predominance of Calcium Oxide in Cement: Calcium oxide makes up 64.7% of Cement but is almost negligible in Fly-Ash and Quarry Dust. This is a crucial component for the setting of cement.

c. Alumina Content: Fly-Ash has a significantly high Alumina content (30.01%) compared to Cement (6.54%) and Quarry Dust (18.72%). Alumina is known for its resistance to chemical attack, which could make Fly-Ash a durable material.

d. Iron Content: All three materials have relatively low Iron content, with Fly-Ash having the highest (9.14%). Iron is often associated with the colour and strength of the material.

e. Missing Elements: Notably, Calcium oxide is absent in Fly-Ash, and Sodium oxide is absent in Quarry Dust. The absence of these elements could influence the setting time and strength of the materials.

f. Loss on Ignition: The LOI values are relatively low for all three materials, indicating minimal organic or volatile impurities.

The result gotten from this test showed the properties of the aggregates and help to know if it was appropriate to use the soil for various civil engineering purposes.

4.2 Specific Gravity

Table 3 outlines the specific gravity of six different construction materials: Sand (fine), Granite (coarse), Quarry Dust, Fly Ash, Glass Fiber, and Cement. Specific gravity is a crucial property that influences the strength, stability, and durability of construction materials.

Table 3: **Specific gravity of sand, quarry-dust, fly-ash, glass fiber and granite**

Materials	Specific gravity
Sand(fine)	2.70
Granite(coarse)	2.71
Quarry dust	2.62
Fly Ash	2.21
Glass Fiber	1.12
Cement	3.05

Some key observations from Table 3 include:

a. **High Specific Gravity of Cement:** Cement has the highest specific gravity (3.05) among the listed materials. This suggests that it is denser and could contribute to the overall strength of a composite material.

b. **Low Specific Gravity of Glass Fiber:** Glass Fiber has the lowest specific gravity (1.12), making it the lightest among the materials. This could be advantageous for applications requiring lightweight yet strong materials.

c. **Close Proximity of Sand and Granite:** The specific gravity of Sand (2.70) and Granite (2.71) are almost identical, indicating that they could be interchangeable in some applications without significantly affecting the density.

d. **Lower Density of Fly Ash:** Fly Ash has a specific gravity of 2.21, which is considerably lower than that of Cement. This could affect its suitability as a full replacement for cement in high-strength applications.

e. **Moderate Specific Gravity of Quarry Dust:** Quarry Dust has a specific gravity of 2.62, placing it between Sand and Fly Ash. This suggests it could be a viable alternative to traditional aggregates.

4.3 Setting Time

Table 4.3 provides information on the setting times of Ordinary Portland Cement (OPC), specifically the Initial Setting Time (IST) and the Final Setting Time (FST). The IST is recorded as 40 minutes, and the FST is 641 minutes.

Table 4: **Results of Setting Times-ST (mins) for (OPC)**

Setting Time	**OPC**
Initial Setting Time	40
Final Setting Time	641

Some key observations from Table 4 include:

a. **Quick Initial Setting Time**: The Initial Setting Time of 40 minutes indicates that OPC begins to harden relatively quickly. This is crucial for construction processes that require rapid setting.

b. **Extended Final Setting Time**: The Final Setting Time of 641 minutes (approximately 10.7 hours) suggests that OPC takes a considerable amount of time to fully harden. This could be both an advantage and a limitation, depending on the application.

4.4 Slump Test

Table 4.4 presents the results of slump tests conducted on various concrete samples containing fly ash and glass fiber. The table includes parameters such as Slump Value (mm), Fully Compacted, Partially Compacted, Compacting Factor, Void (%), and Pressure (bar).

Table 5: Slump test results on concrete containing fly ash and glass fiber

Samples Name	Slump value (mm)	Fully Compacted	Partially Compacted	Compacting Factor	Void (%)	Pressure (bar)
M01	60.20	18.00	17.70	0.3	3.00	2.00
M02	40.20	18.00	17.80	0.2	2.50	2.50
M03	55.70	18.10	17.90	0.2	2.50	2.50
M04	60.30	18.00	17.80	0.2	2.00	2.00
MF0	62.50	17.70	16.50	1.2	2.50	2.50
MF1	63.10	18.00	17.90	0.1	2.00	2.50
MF2	70.10	18.00	17.70	0.3	2.50	2.00
MF3	72.00	18.20	18.00	0.2	1.50	2.00
2MF0	65.50	18.10	17.90	0.2	2.00	1.50
2MF1	71.00	18.00	17.70	0.3	4.00	2.00
2MF2	72.00	18.00	17.80	0.2	2.00	2.50
2MF3	63.00	18.10	17.90	0.2	2.50	2.50
3MF0	82.50	18.00	17.70	0.3	1.50	3.00
3MF1	71.30	17.60	17.20	0.4	2.00	2.00
3MF2	70.20	17.70	16.60	1.1	3.00	2.50
3MF3	63.20	18.00	17.80	0.2	2.50	2.50

Some key observations from Table 5 include:

a. Variability in Slump Values: The slump values range from 40.20 mm (M02) to 82.50 mm (3MF0), indicating a wide range of workability among the samples.

b. Consistency in Compaction: The Fully Compacted and Partially Compacted values are relatively consistent across samples, suggesting uniform compaction properties.

c. Low Compacting Factors: Most samples have a compacting factor of 0.2 or 0.3, except for MF0 and 3MF2, which have higher values of 1.2 and 1.1, respectively.

d. Varying Void Percentages: The void percentages range from 1.50% to 4.00%, with 2MF1 having the highest void percentage.

e. Uniform Pressure Values: The pressure values are generally consistent, ranging from 1.50 to 3.00 bar, indicating similar resistance to pressure across samples.

Table 6 provides detailed slump test results on concrete samples labelled M and MQ. The parameters measured include Slump Value (mm), Fully Compacted, Partially Compacted, Compacting Factor, Void (%), and Pressure (bar).

Table 6: Slump test results on concrete containing quarry-dust and glass fiber

Samples Name	Slump value (mm)	Fully Compacted	Partially Compacted	Compacting Factor	Void (%)	Pressure (bar)
M01	70.00	18.00	17.60	0.4	3.00	2.50
M02	69.00	18.10	17.50	0.6	2.50	2.00
M03	70.00	18.30	18.20	0.1	2.00	2.50
M04	71.00	17.80	17.30	0.5	2.00	2.00

MQ0	65.00	18.10	17.70	0.4	3.00	2.00
MQ1	67.00	18.30	18.10	0.2	2.00	2.50
MQ2	70.00	18.00	17.70	0.3	2.00	2.50
MQ3	63.00	17.50	17.30	0.2	2.50	2.00
2MQ0	70.00	18.00	17.80	0.2	2.50	2.50
2MQ1	69.00	18.10	17.70	0.4	3.00	2.50
2MQ2	70.00	18.00	17.90	0.1	3.00	2.00
2MQ3	75.00	18.10	17.80	0.3	2.50	2.00
3MQ0	85.00	17.70	17.30	0.4	2.00	2.50
3MQ1	83.00	17.90	17.60	0.3	2.00	2.50
3MQ2	78.00	18.00	17.80	0.2	2.00	2.00
3MQ3	79.00	18.00	17.80	0.2	2.00	2.00

Some key observations from Table 6 include:

a. Slump Value Consistency: The slump values for both M and MQ series are relatively consistent, ranging from 63.00 mm (MQ3) to 85.00 mm (3MQ0). This suggests a moderate to high level of workability across the samples.

b. Compaction Uniformity: The Fully Compacted and Partially Compacted values are fairly consistent, indicating that the concrete samples have similar compaction characteristics.

c. Compacting Factor Variability: The compacting factors range from 0.1 (M03, 2MQ2) to 0.6 (M02), indicating varying degrees of compatibility.

d. Void Percentage: The void percentages are mostly around 2.00% to 3.00%, suggesting moderate porosity levels in the samples.

e. Pressure Resilience: Pressure values are fairly consistent, ranging from 2.00 to 2.50 bar, which indicates similar resistance to pressure across the samples.

Table 7 presents the slump test results for concrete samples labeled M and MQF. The parameters include Slump Value (mm), Fully Compacted (kg), Partially Compacted (kg), Compacting Factor (kg), Void (%), and Pressure (bar).

Table 7: Slump test results for quarry-dust, fly-ash and glass fiber

Samples Name	Slump value (mm)	Fully Compacted (kg)	Partially Compacted (kg)	Compacting Factor (kg)	Void (%)	Pressure (bar)
M01	60.00	18.00	17.70	0.3	2.5	2.0
M02	73.00	17.60	17.20	0.4	2.0	1.5
M03	80.00	18.00	17.20	0.8	2.0	2.0
M04	79.00	17.70	17.50	0.2	2.0	2.0
MQF0	65.00	18.00	17.90	0.1	2.5	2.5
MQF1	79.00	18.00	17.60	0.4	3.0	1.5
MQF2	77.00	18.00	17.70	0.3	1.5	2.0
MQF3	56.00	18.10	18.00	0.1	1.5	2.5
2MQF0	60.00	18.00	17.80	0.2	2.0	2.0

2MQF1	80.00	18.00	17.60	0.4	2.0	1.5
2MQF2	75.00	18.00	17.80	0.2	2.0	2.0
2MQF3	77.00	18.00	17.90	0.1	2.5	2.0
3MQF0	81.00	17.90	17.80	0.1	3.0	2.5
3MQF1	79.00	18.00	17.50	0.5	3.0	2.5
3MQF2	82.00	18.00	17.90	0.1	2.5	2.5
3MQF3	77.00	18.10	17.80	0.3	2.5	2.5

Some key observations from Table 7 include:

a. Slump Value Range: The slump values range from 56.00 mm (MQF3) to 82.00 mm (3MQF2), indicating a wide spectrum of workability among the samples.

b. Consistency in Compaction: The Fully Compacted and Partially Compacted values are relatively uniform, suggesting that the concrete samples have similar compaction characteristics.

c. Variable Compacting Factors: The compacting factors vary from 0.1 (MQF0, MQF3, 2MQF3, 3MQF0, 3MQF2) to 0.8 (M03), indicating different levels of compactability.

d. Void Percentages: The void percentages are generally between 1.5% and 3.0%, suggesting moderate levels of porosity.

e. Pressure Resilience: Pressure values are fairly consistent, ranging from 1.5 to 2.5 bar, indicating similar resistance to pressure across samples.

Figure 1 and Tables 5 to 7 show the slump test result of concrete made with fly-ash, quarry-dust and glass-fiber and the results indicate that concrete made with quarry-dust and glass fiber is more workable compared to that of concrete made with a mixture of fly-ash, quarry-dust and glass fiber and fly-ash and glass fiber.

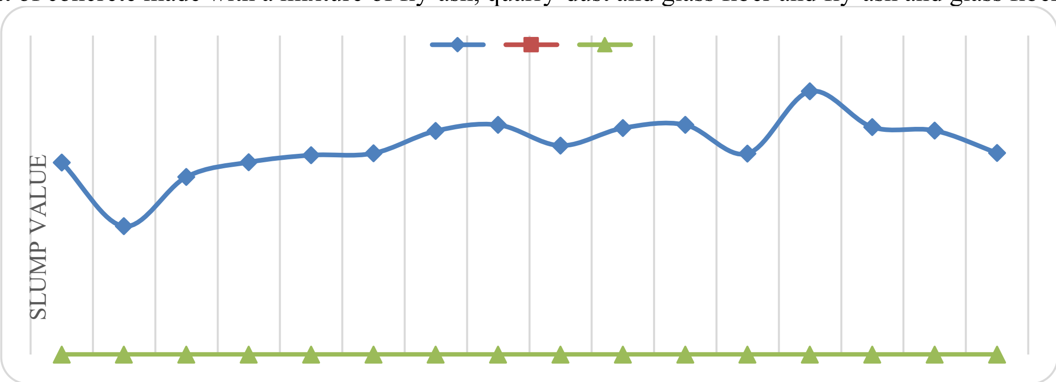

Figure 1: Slump test for fly-ash, quarry-dust and glass fiber

4.5 Particle Size Distribution of Aggregates

Table 8 presents the results of a sieve analysis test conducted on sand. The parameters include Sieve Sizes (mm), Sample Weight Retained (g), Percentage Retained (g), and Percentage Passing.

Table 8: Sieve analysis test results on Sand

Sieve sizes (mm)	Sample weight retained (g)	% Retained (g)	% Passing
5.00	0.00	0.00	100.00
4.00	1.70	0.85	99.15
3.00	0.50	0.25	98.90

2.36	16.50	8.25	90.65
1.70	5.30	2.65	88.00
0.60	30.30	15.15	72.85
0.50	15.40	7.70	65.15
0.212	83.00	41.50	23.65
0.150	20.10	10.05	13.60
0.075	15.20	7.60	6.00
Pan	12.00	6.00	0.00

Some key observations include:

a. **No Retention at Larger Sieve Sizes**: There is zero retention at the 5.00 mm sieve size, indicating that the sand sample contains no particles larger than this size.

b. **High Retention at Smaller Sieve Sizes**: The highest retention occurs at the 0.212 mm sieve size, with 41.50% of the sample retained.

c. **Significant Passing at Larger Sieve Sizes**: 100% of the sample passes through the 5.00 mm sieve, and the percentage passing gradually decreases as the sieve size becomes smaller.

d. **Lowest Passing at Smallest Sieve Size**: Only 6.00% of the sample passes through the 0.075 mm sieve, indicating a low presence of fine particles.

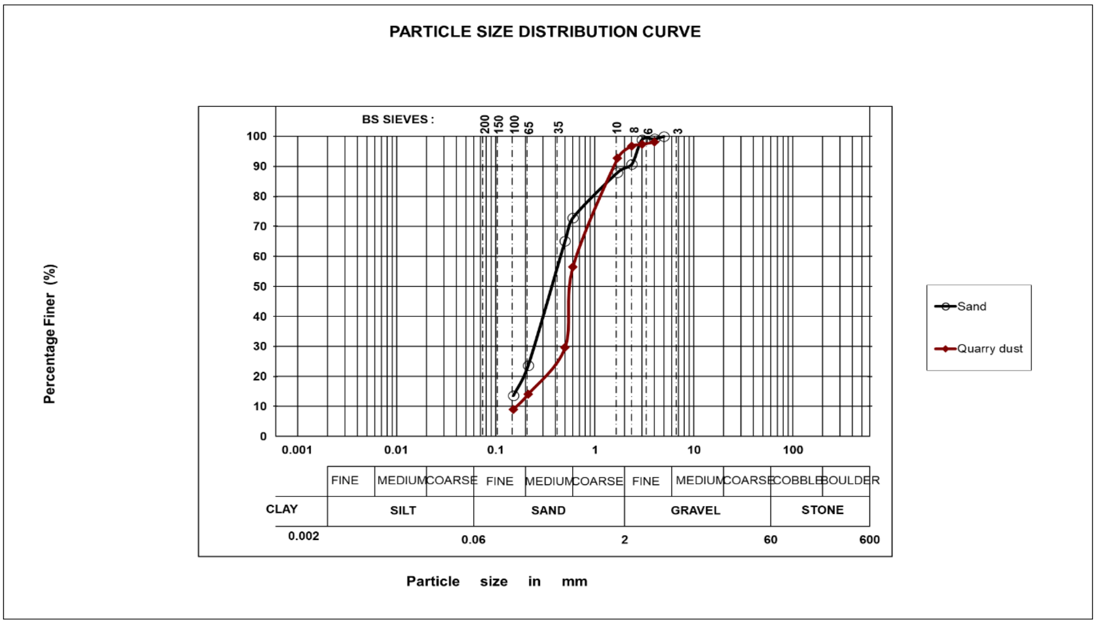

Figure 2: Particle Size Distribution Curve for Fine aggregates

4.6 Compressive Strength

Table 9 shows the compressive strength test results of concrete containing quarry dust replacing sand in varied percentages at 10%, 20% and 30% while incorporating glass fibers in different percentages at 1%, 2% and 3% after curing for 7, 14, 21 and 28 days.

Table 9: Compressive strength result of concrete containing quarry dust and glass fiber at 0.5 w/c ratio

Sample	Sand (%)	Quarry dust (%)	Glass fiber (%)	Compressive Strength @7days (N/mm2)	Compressive Strength @ 14days (N/mm2)	Compressive Strength @ 21days (N/mm2)	Compressive Strength @ 28days (N/mm2)
M01	100		0	8.73	12.12	15.49	23.55
M02	100		1	8.75	12.10	16.54	23.84
M03	100		2	8.92	12.54	16.85	23.72
M04	100		3	8.60	12.72	17.03	23.87
MQO	90	10	0	8.81	12.59	15.60	22.86
MQ1	90	10	1	8.67	13.05	15.92	23.11
MQ2	90	10	2	8.96	13.66	17.29	23.95
MQ3	90	10	3	8.94	13.59	17.16	23.29
2MQ0	80	20	0	8.86	13.39	16.71	22.44
2MQ1	80	20	1	9.07	13.80	16.63	23.75
2MQ2	80	20	2	9.72	14.02	18.12	24.32
2MQ3	80	20	3	9.51	13.50	16.95	24.06
3MQ0	70	30	0	8.46	12.93	15.66	21.66
3MQ1	70	30	1	9.04	13.86	15.38	20.48
3MQ2	70	30	2	8.90	13.49	16.94	21.84
3MQ3	70	30	3	8.77	13.16	16.19	20.56

The results as shown on the table revealed that:

a. **Compressive Strength Increase Over Time**: All samples show an increase in compressive strength from 7 to 28 days, which is consistent with the general understanding of concrete curing (Mehta & Monteiro, 2014).

b. **Influence of Quarry Dust**: The samples with 10% and 20% quarry dust (MQ and 2MQ series) generally exhibit higher compressive strength at 28 days compared to those with 100% sand (M series).

c. **Glass Fiber Addition**: The addition of glass fiber (1-3%) does not show a consistent trend in affecting compressive strength. However, it's worth noting that 2MQ2 with 2% glass fiber shows the highest compressive strength at 28 days.

d. **Lower Sand Content**: The 3MQ series, with the lowest sand content (70%), generally shows lower compressive strength at 28 days compared to other series.

The use of quarry dust in the MQ and 2MQ series suggests potential cost savings and waste reduction without compromising strength. Although, the varying compressive strengths indicate that careful selection of materials is essential for achieving desired structural properties.
Finally, the use of waste materials like quarry dust could contribute to more sustainable construction practices.

From figure 3, the highest average compressive strength of concrete was noticed in 2MQ2 on the 28 days and the lowest average compressive strength was noticed in 3MQ0 on the 7 days.

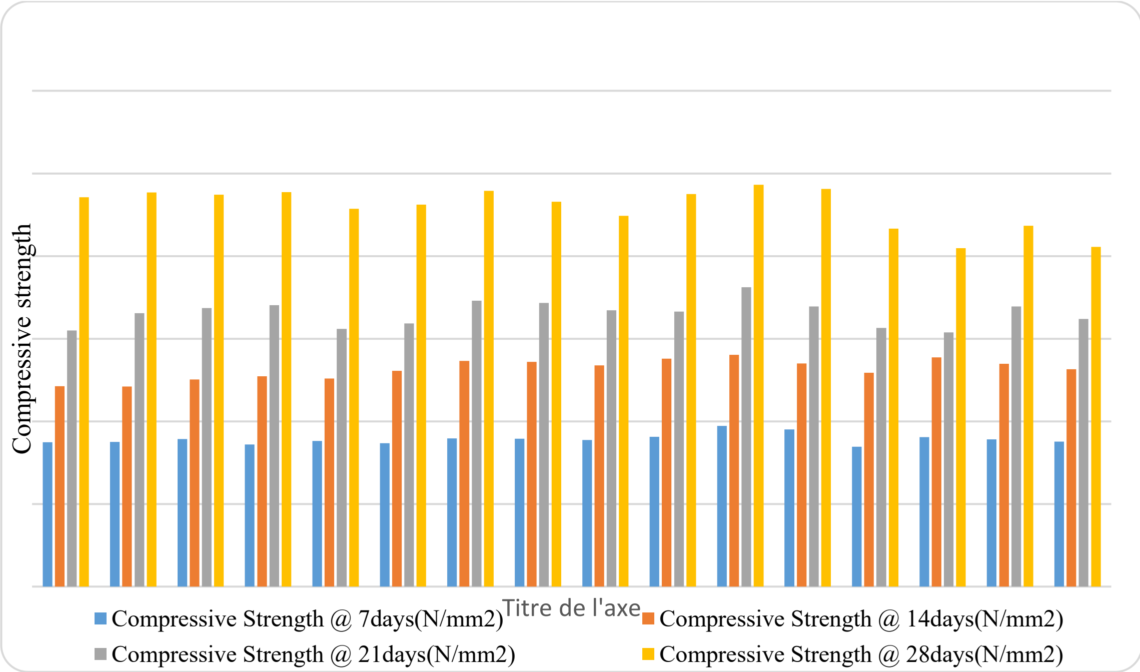

Figure 3: Compressive strength of concrete containing quarry-dust and glass fiber.

Table 10 shows the compressive strength test results of concrete containing fly ash replacing cement in varied percentages at 10%, 20% and 30% while incorporating glass fibers in different percentages at 1%, 2% and 3% after curing for 7, 14, 21 and 28 days

Table 10: Compressive strength result of concrete containing fly-ash and glass fiber at 0.5 w/c ratio

Sample	Cement (%)	Fly ash (%)	Glass fiber (%)	Compressive Strength @ 7days (N/mm2)	Compressive Strength @ 14days (N/mm2)	Compressive Strength @ 21days (N/mm2)	Compressive Strength @ 28days (N/mm2)
M01	100		0	8.73	12.12	15.49	23.55
M02	100		1	8.75	12.10	16.54	23.84
M03	100		2	8.92	12.54	16.85	23.72
M04	100		3	8.60	12.72	17.03	23.87
MFO	90	10	0	8.50	12.19	17.25	22.68
MF1	90	10	1	8.53	12.24	18.47	23.43
MF2	90	10	2	8.56	12.86	17.87	22.81
MF3	90	10	3	9.04	13.12	18.34	23.02
2MF0	80	20	0	9.18	12.94	18.03	23.55
2MF1	80	20	1	9.25	13.20	18.70	24.52
2MF2	80	20	2	9.55	13.46	18.95	24.74
2MF3	80	20	3	9.25	13.38	18.34	24.11
3MF0	70	30	0	8.83	12.71	16.51	22.36
3MF1	70	30	1	8.87	12.95	17.97	22.59
3MF2	70	30	2	8.93	12.84	16.86	22.11
3MF3	70	30	3	8.79	12.45	16.04	21.74

Table 10 shows the compressive strength test results of concrete containing fly ash replacing cement in varied percentages at 10%, 20% and 30% while incorporating glass fibers in different percentages at 1%, 2% and 3% after curing for 7, 14, 21 and 28 days. The results from the table showed that:

a. **Compressive Strength Increase Over Time**: All samples show an increase in compressive strength from 7 to 28 days, aligning with the general understanding of concrete curing (Mehta and Monteiro, 2014).

b. **Fly Ash Impact**: Samples with 10% and 20% fly ash (MF and 2MF series) generally exhibit higher compressive strength at 28 days compared to those with 100% cement (M series).

c. **Glass Fiber Addition**: The addition of glass fiber (1-3%) generally results in higher compressive strength, particularly noticeable in the 2MF series.

d. **Lower Cement Content**: The 3MF series, with the lowest cement content (70%), generally shows lower compressive strength at 28 days compared to other series.

The use of fly ash in the MF and 2MF series suggests potential cost savings and waste reduction without compromising strength. Also, the use of waste materials like fly ash could contribute to more sustainable construction practices.

Figure 4, the highest average compressive strength was noticed in 2MF2 at 28 days and the lowest average compressive strength was noticed in MF0 at 7 days.

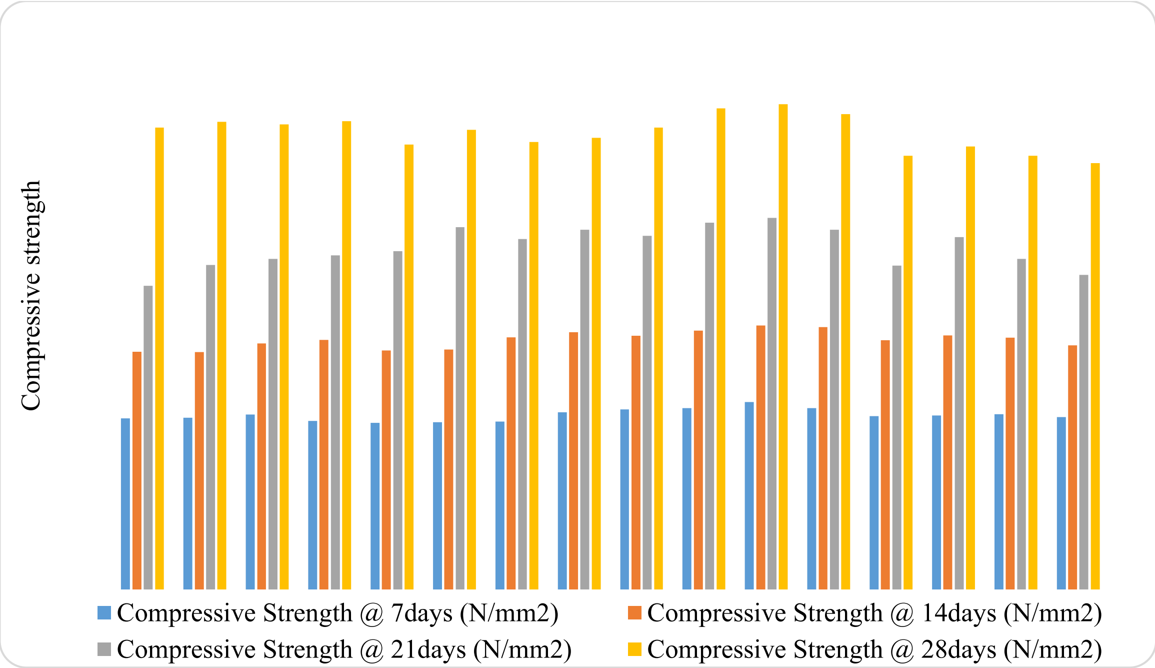

Figure 4: Compressive strength of concrete containing fly-ash and glass fiber.

Table 11 shows the compressive strength test results of concrete containing a combination of fly ash, quarry dust replacing cement and sand in varied percentages at 5%, 10% and 15% each while incorporating glass fibers in different percentages at 1%, 2% and 3% after curing for 7, 14, 21 and 28 days.

Table 11: Compressive strength of concrete containing fly ash, quarry dust and glass fiber at 0.5 w/c ratio

Sample	Cement (%)	Sand (%)	Fly ash (%)	Quarry dust (%)	Glass fiber (%)	Compressive Strength @ 7days (N/mm2)	Compressive Strength @ 14days (N/mm2)	Compressive Strength @ 21days (N/mm2)	Compressive Strength @ 28days (N/mm2)
M01	100	100			0	8.73	12.12	15.49	23.55
M02	100	100			1	8.75	12.10	16.54	23.84
M03	100	100			2	8.92	12.54	16.85	23.72
M04	100	100			3	8.60	12.72	17.03	23.87
MQFO	95	95	5	5	0	8.79	13.21	16.29	22.44
MQF1	95	95	5	5	1	9.16	13.17	18.47	21.74
MQF2	95	95	5	5	2	9.38	13.73	19.72	21.57
MQF3	95	95	5	5	3	9.04	12.86	17.76	21.24
2MQF0	90	90	10	10	0	9.03	12.83	17.69	23.75
2MQF1	90	90	10	10	1	9.49	13.03	19.41	24.11
2MQF2	90	90	10	10	2	8.81	13.85	19.25	24.89
2MQF3	90	90	10	10	3	8.33	13.61	19.45	24.47
3MQF0	85	85	15	15	0	9.13	12.09	17.28	22.12
3MQF1	85	85	15	15	1	9.46	12.95	17.72	23.52
3MQF2	85	85	15	15	2	8.52	12.09	17.56	23.70
3MQF3	85	85	15	15	3	8.67	12.13	17.63	24.53

The results showed that:

a. **Compressive Strength Over Time**: All samples exhibit an increase in compressive strength over time, which is consistent with the well-established curing behaviour of concrete (Mehta & Monteiro, 2014).

b. **Effect of Admixtures**: The samples with fly ash, quarry dust, and glass fiber (MQF, 2MQF, 3MQF series) generally show competitive or even superior compressive strength compared to the control samples (M series) at 28 days.

c. **Glass Fiber Impact**: The addition of glass fiber (1-3%) seems to positively influence the compressive strength, especially in the 2MQF and 3MQF series.

d. **Quarry Dust and Fly Ash**: The samples with 10% and 15% of quarry dust and fly ash (2MQF and 3MQF series) show a higher compressive strength at 28 days compared to those with 5% (MQF series).

Table 11 also suggests that the inclusion of fly ash and quarry dust can be an effective way to maintain or even improve compressive strength, thereby contributing to sustainable construction. The use of waste materials like quarry dust and fly ash could lead to cost savings without compromising structural integrity.
Finally, the addition of glass fiber appears to enhance the compressive strength, which could be beneficial in applications requiring high-strength concrete.

From Figure 5, the highest average compressive strength was noticed in 2MF2 at 28 days and the lowest average compressive strength was noticed in 3MQF2 at 7 days.
Concrete made with quarry dust and glass fiber produces the highest compressive strength at 2MQ2 followed by 2MQ3 and MQ2 to be 24.32N/mm^2**,** 24.06N/mm^{2}and 23.95N/mm^2 respectively at 28 days. While concrete made with fly ash and glass fiber has the highest compressive strength 2MF2 followed by 2MF1 and 2MF3 to be 24.74N/mm^2**,** 24.52N/mm^2 and 24.11N/mm^2 respectively at 28 days and concrete produced from fly ash, quarry dust and glass fiber has the highest compressive strength at 2MQF2 followed by 3MQF3 and 2MQF3 to be 24.89N/mm^2**,** 24.53N/mm^{2}and 24.47N/mm^{2}respectively at 28 days. The results further show that the compressive strength of concrete produced increase with increase in curing ages.

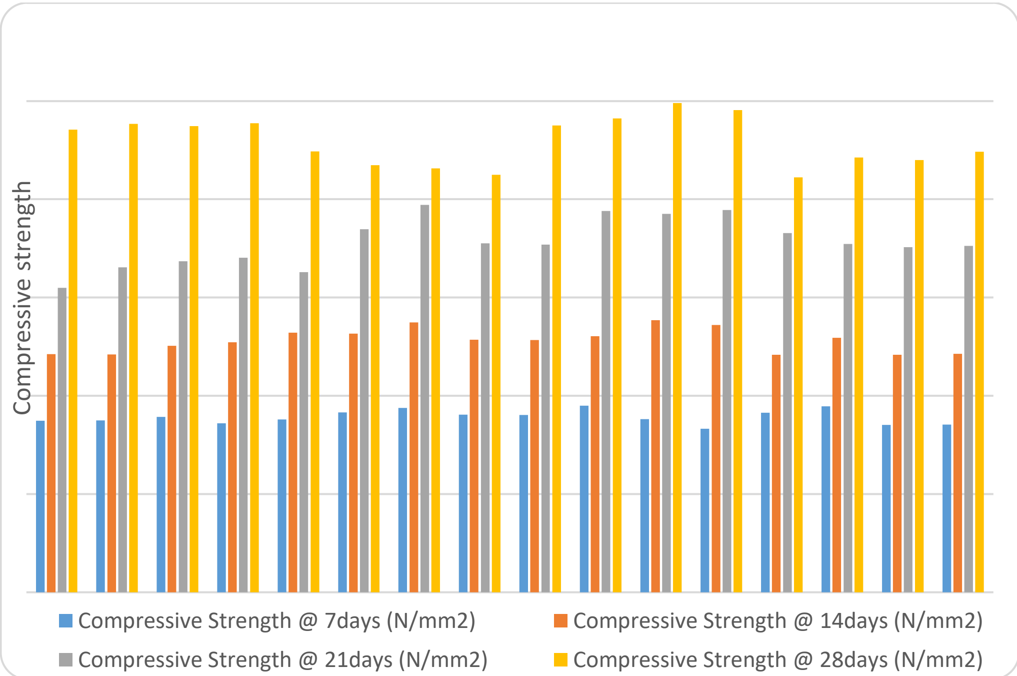

Figure 5: Compressive strength of concrete containing fly ash, quarry dust and glass fiber.

4.7 Regression Analysis Result

Table 12 shows the result of the regression analysis conducted on the experimental data obtained using the regression analysis toolpak in Microsoft Excel 2016 package.

Table 12: Regression Analysis Result

Regression Statistics	
R Square	0.898
Adjusted R Square	0.875
Standard Error	2.5702
Observations	48

ANOVA

	Df	*SS*	*MS*	*F*	*Significance F*
Regression	3	240.540	80.180	12.138	6.44E-06
Residual	44	290.660	6.606		
Total	47	531.199			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	26.078	0.796	32.775	0.000	24.474			
Quarry dust	0.068	0.041	1.649	0.005	-0.015	27.681	24.474	27.681
Fly-ash	0.979	0.332	2.950	0.005	0.310	0.151	-0.015	0.151
Glass-Fibers	0.216	0.041	5.263	0.000	0.134	1.648	0.310	1.648
						0.299	0.134	0.299

From table 12, the model obtained between compressive strength, volume of glass fibers, percentage quarry dust and percentage fly-ash was:

$$CS = 0.216V_{gf} + 0.068V_{qd} + 0.979V_{fa} + 26.078 \quad (2)$$

Where:

CS	is	Compressive Strength
V_{gf}	is	Volume of glass fibers
Vqd	is	Volume of quarry dust
V_{fa}	is	Volume of fly-ash

Using equation 2, it can be deduced that the volume of fly-ash had the highest influence on the compressive strength with a coefficient value of 0.979 compared with 0.216 and 0.068 of glass fibers and quarry dust. It also showed that glass fibers had significant influence on concrete compressive strength compared to quarry dust.

The R-Square and the P-value which is the most important of the regression parameters are a measure of how effective the model independent variables (volume of fly-ash, volume of quarry dust and volume of glass fibers) measure the dependent variable (Compressive strength). The R-Square and the P-value should not exceed 0.5, both of which was applicable from their respective values of 0, 0.005, 0, 0.005 respectively. The F significancy showed how significant the model is. The closer to zero its value is, the more significant the model is. The F-significance value of 0.00000644 showed a high level of significancy.

5. CONCLUSION

The following conclusions were made from the research:

a. The optimal combination of fly ash for partial cement replacement in concrete is 20% fly-ash with 80% cement, 100% sand and 100% coarse aggregates at 2% glass fibers with a compressive strength of 24.74N/mm^2

b. The optimal quarry dust combination for partial sand replacement in concrete is 20% quarry dust with 80% sand, 100% cement and 100% coarse aggregates at 2% glass fibers with a compressive strength of 24.32N/mm^2
c. The optimal combination of quarry dust and fly-ash for partial cement and sand replacement in concrete is 10% quarry dust with 10% fly ash with 90% cement, 90% sand and 100% coarse aggregates at 2% glass fibers with a compressive strength of 24.89N/mm^2.
d. The 24.89N/mm^2 optimal concrete compressive strength of 10% quarry dust with 10% fly-ash at 2% Glass fibers is higher than the optimal compressive strength of fly-ash with glass fibers only and quarry dust with glass fibers only by 0.15N/mm^2 and 0.57N/mm^2 respectively. This gives the optimal compressive strength of concrete containing quarry dust, fly-ash and glass fibers.
e. The model showing the relationship between compressive strength and quarry dust, glass fibers and fly-ash was:

6. $CS = 0.216V_{gf} + 0.068V_{qd} + 0.979V_{fa} + 26.078$
7. Where V_{gf} is volume of glass fibers, V_{qd} is volume of quarry dust and V_{fa} is volume of fly-ash.

f. From the model, fly-ash has the highest influence on the concrete compressive strength with a coefficient value of 0.979, followed by glass fibers at 0.216 and lastly, the quarry dust.

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