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A Study on Mechanical Properties of Concrete Incorporating Aluminum Dross, Fly Ash, and Quarry Dust

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Abstract: The amount of waste, associated waste disposal costs, and environmental contamination may be minimized by identifying effective recycling approaches. These promising approaches will also lead to the protection of natural resources and economic gains. One example of waste disposal maybe by using it as a filling material or as a pozzolanic material for the production of concrete. In this regard, this study proposes to partially replace cement with aluminum dross and fly ash, and partially replace natural sand with quarry dust. Aluminum dross, cement, sand, and quarry dust were used in a variety of proportions with a constant percentage of fly ash for the design of nine concrete mixtures. Aluminum dross was replaced by 5, 10, 15, and 20% of the cement mass. At first, the optimum replacement of aluminum dross without using quarry dust was determined at a constant percentage of fly ash-15% based on the strength results. Later, by introducing the optimum substitution of aluminum dross with cement and fly ash, the quarry dust was partially replaced at 10, 20, 30, and 40% of river sand to determine the overall optimum mix. The mechanical and durability characteristics of the concrete using the three mixtures were analyzed. It has been observed that the mechanical and durability characteristics of a concrete mixture incorporating a fly ash-15%, aluminum dross-10%, and quarry dust-20% are better than that of standard concrete. Production of concrete using industrial waste can minimize infrastructure construction costs and reduce environmental impacts.

Keywords: hazardous waste; aluminum dross; concrete; quarry dust; fly ash; compressive strength; water absorption

1. Introduction

Today, with economic growth and improved living standards, the world is witnessing the large-scale construction of buildings, resulting in high demand for building materials. Concrete is the most common material used in construction. Cement and natural river sand are the two main components of concrete. Cement production contributes about 8% of the global emissions of anthropogenic CO_2 [1]. In addition, the extraction of river sand causes various problems, such as riverbank erosion, deterioration of riverbeds, intrusion of river buffer zones, and a decline in water quality. A sustainable approach in the construction industry should be introduced to address these problems. In other words, alternative building materials made from industrial waste or recycled

materials can be substituted for the regular components of concrete. Integrating sustainability into the construction industry is essential for the protection of the environment, improving air quality, managing solid waste, and preserving natural resources [2]. Industrial production is affected by major problems such as waste generation and the depletion of natural resources. Industrial waste accumulates over time and causes significant damage to the environment and to human health [3]. The amount of waste, associated disposal costs, and environmental damage could be minimized by finding appropriate recycling strategies. Such a promising strategy can also lead to the preservation of natural resources and economic advantages [4].

2. Literature Review

Day after day, due to ecological concerns, the use of waste such as fly ash, quarry dust, silica smoke, rice husk ash, and other materials is becoming increasingly valuable in the production of concrete. Various studies have investigated the use of fly ash, aluminum dross, rice husk ash, and silica smoke as a partial replacement material for cement in concrete. Santamaria et al. [5] has observed that a high quality of concrete mixes in terms of workability and mechanical strength was provided using Electric Arc-Furnace slag. Saha [6] studied the effect of class F fly ash on the durability of concrete. As a result, concrete samples usually contain fly ash, which is found to have low early compressive strength compared to control samples. However, the compressive strength was improved greatly over a longer time due to a pozzolanic reaction, while control samples stopped growing after 56 days of curing. In addition, with the increase in the content of the fly ash in the mixture, the shrinkage of the drying was reduced. Ultra-pulverized fly ash and superplasticizer concrete have lower permeability levels, are ideal for freeze-thaw resistance, and have lower drying shrinkage [7]. Huang et al. [8] observed that fly ash enhanced strength and increased the setting time for concrete at around 91 and 365 days of age.

As hazardous solid residues in aluminum production industries, aluminum dross causes serious environmental and public health challenges. Another practical way to avoid the issue of dross disposal is to use aluminum dross in building applications such as cement or sand substitution in producing concrete blocks and aluminum cement [4]. Elinwa and Mbadike [9] manufactured concrete by substituting various aluminum waste percentages of cement. The results found that the compressive and flexural strengths of concrete were similar to those of conventional concrete with replacement rates of 10–15%. The other discovery was that aluminum concrete retards the setting times of concrete that are beneficial in hot weather conditions.

Aluminum dross has been suggested to be used in the production of eco-concrete in the study by Javali et al. [10]. They have produced several mixtures of Portland cement, aluminum dross, sand, and granular iron slag. For aluminum dross, different replacement levels were considered with 5%, 10%, 15%, and 20% wt., and the optimal substitution level was determined with 5% wt. The strength and durability analysis shows that eco-concrete, which is made of aluminum 5% wt. and iron slag 20% wt., may compete with normal cement. The mechanical characteristics of Portland cement mortar have been investigated by Pereira et al. [11] and found that aluminum dross may be applied in small quantities for cement replacement. The compressive strength of the concrete decreases with an increase in the replacement of the aluminum dross. They found that the amount of dross used in concrete should not exceed 15%. In their research on the mechanical properties and durability of aluminum dross-containing concrete, Reddy and Neeraja [12] reported that the results were comparable to conventional concrete with cement substitution for secondary aluminum dross up to 15%. Their overall results indicate that the addition of additional cement-based materials such as fly ash and silica fume in various proportions along with aluminum dross improves the pozzolanic reaction of concrete, which enhances strength and durability.

In recent years, the unsustainable approach to the use of river sand has led to its depletion and a significant environmental impact. The construction industry is therefore seeking alternatives from by-products or recycled fine aggregate materials to replace sand in concrete production. Quarry dust is the waste produced by the granite crushing process. Once dried, fine dust is produced, causing serious

human health problems as well as serious environmental threats to soil and water contamination [13]. Mir [14] noted that the ability to adapt to quarry dust as a sand substitute material, and it demonstrated that the mechanical properties and the elastic modulus had been increased. The compressive strength was improved by replacing fine aggregates with quarry dust at a ratio of 60:40. In the construction industry, concrete containing quarry dust as a fine aggregate with good quality ingredients, an adequate dosage of superplasticizers, effective mixing procedures, and proper curing can be used to ensure sustainable development [15].

Chitlange and Pajgade [16] found that the strength of plain concrete was gradually rising as natural sand was completely replaced by quarry dust. Ephraim et al. [17] reported in their work that they used lateral sand and quarry dust for the production of concrete as a partial replacement of fine aggregates. As a result, it was found that both flexural and split tensile strength had been enhanced.

In this regard, the present paper aims to use industrial waste materials as alternative building materials in order to reduce both environmental pollution and construction costs. In order to do so, this study proposes the use of three types of waste for the production of sustainable concrete (aluminum dross, fly ash, and quarry dust). Aluminum dross and quarry dust are to be used as a partial substitute for ordinary Portland cement and river sand. A constant quantity of fly ash (i.e., 15% of cement mass) is developed to increase the workability, durability, and mechanical properties of concrete with aluminum dross and quarry dust. To date, however, the mixture of the three waste materials mentioned has not been studied together in the literature.

3. Materials and Methods

3.1. Cement

In this research work, ordinary Portland cement (OPC) grade CEM–I–52.5N was used in accordance with ASTM C 150-00 [18] and MS EN 197-1:2014 [19]. The specific gravity of the cement was 3.15, and the bulk density was 1440 (kg/m^3). The characteristics of cement as specified by the manufacturer are shown in Table 1, whereas the chemical composition of the OPC is tabulated in Table 2, which was carried out by X-ray Fluorescence (XRF).

Table 1. Characteristics of cement.

Description	Unit	MS EN 197-1:2014 CEM I 52.5 N	OPC CEM I 52.5 N Grade
Chemical composition	-	-	-
Chloride content (Cl)	%	0.1 max.	0.01
Loss in ignition (LOI)	%	5.0 max.	3.3
Insoluble residue	%	5.0 max.	0.5
Sulphate content (SO_3)	%	3.5 max.	3.0
Physical properties	-	-	-
Soundness	mm	10 max.	0.5
Specific surface by Blaine	cMix2/g	-	4022
Setting time	-	-	-
Initial	min	45 min.	136
Final	min	600 max.	190
Compressive strength	-	-	-
2 days	MPa	10.0 min.	27.1
28 days	MPa	52.5 min.	57.1

Note: Min. is minimum, Max. is maximum. OPC: Ordinary Portland cement

3.2. Aluminum Dross

The aluminum dross (AD) used in this study was provided by Cenviro Sdn Bhd, Kuala Lumpur, Malaysia. The shape of the dross is irregular, with a black color containing lumps and small pieces of aluminum. The aluminum (Al) dross had a specific gravity of 3.39 and a bulk density of 774 kg/m^3.

Due to the pozzolanic activity of Al dross [12], it can be used as a filler for the production of concrete by partial replacement of cement. Al dross passes a sieve of 100 µm before being used for the production of concrete.

Treatment of Raw Aluminum Dross

In a study conducted by Pereira et al. [11], it noted that the raw aluminum slag mortar produced showed a noticeable increase in volume. Thus, the use of aluminum slag without prior washing is impractical. In the present work, the aluminum dross used was introduced into a container containing distilled water; the solid-to-liquid ratio was maintained at 1:6. The mixture of aluminum dross and distilled water was stirred at room temperature for 30 min to remove alkaline and inorganic salts from the aluminum dross sample. Undissolved aluminum dross is removed by vacuum filtration and then dried in an oven at 100 °C for 12 hrs. The washing procedure was based on the literature of Javali et al. [10] and Pereira et al. [11]. The chemical composition of the treated aluminum dross is shown in Table 2.

Table 2. Chemical composition of cement, aluminum dross, and fly ash.

Property	OPC (%)	Aluminum Dross (%)	Fly Ash (%)
Alumina (Al_2O_3)	6	19.96	27
Lime (CaO)	62	18.09	4
Iron oxide (Fe_2O_3)	4	0.41	29
Magnesium oxide (MgO)	0.8	0.52	0.6
Silica (SiO_2)	22	57.81	61

3.3. Fly Ash

The class F fly ash used in this study was collected from Jimah Power Plant, Selangor, Malaysia. The generation of more cementitious compounds is one of the most valuable advantages of fly ash. According to a pozzolanic reaction [20], fly ash reacts with the lime and alkali available in concrete and produces calcium silicate hydrate (C-S-H). Table 2 presents the chemical composition of fly ash that was assessed using X-ray Fluorescence (XRF).

3.4. Fine Aggregate

3.4.1. River Sand

The fine aggregate used in this analysis was natural river sand compliant with MS EN 12620:2010 [21]. The physical properties of river sand, like specific gravity (ASTM-D2487) [22], water absorption, fineness modulus, moisture content, and bulk density, are shown in Table 3.

Table 3. Physical characteristics of river sand and quarry dust.

Property	River Sand	Quarry Dust
Specific gravity	2.64	2.75
Fineness modulus	2.32	2.40
Moisture content (%)	1.14	1.23
Water absorption (%)	1.11	2.91
Bulk density (kg/m^3)	1420	1730

3.4.2. Quarry Dust

The quarry dust is a by-product of the crushing process in quarrying operations and is used in this analysis by partial replacement with natural river sand. The grain size of the quarry dust conforms to the classification of ASTM C 33-00 [18]. The physical properties of quarry dust, such as

basic gravity (ASTM-D2487) [22], water absorption, fineness modulus, moisture content, and bulk density, are shown in Table 3.

3.5. Coarse Aggregate

In this study, crushed granite was used as a coarse aggregate conforming to ASTM C 33-00 [18]. The coarse aggregate had a size of 20 mm, a specific gravity of 2.77, and a water absorption of 1.27%.

3.6. Water and Superplasticizer

Water plays an important role in the mixing and curing of concrete. Clean drinking water, free of any harmful plastic materials and hardened concrete, has been used in accordance with MS EN 1008:2010 [21]. A polycarboxylate-based superplasticizer is used at an optimum dosage of less than 0.1% of cement weight to reduce the water content of all concrete mixtures by 25%.

3.7. Procedure

The experimental work design is shown in Figure 1.

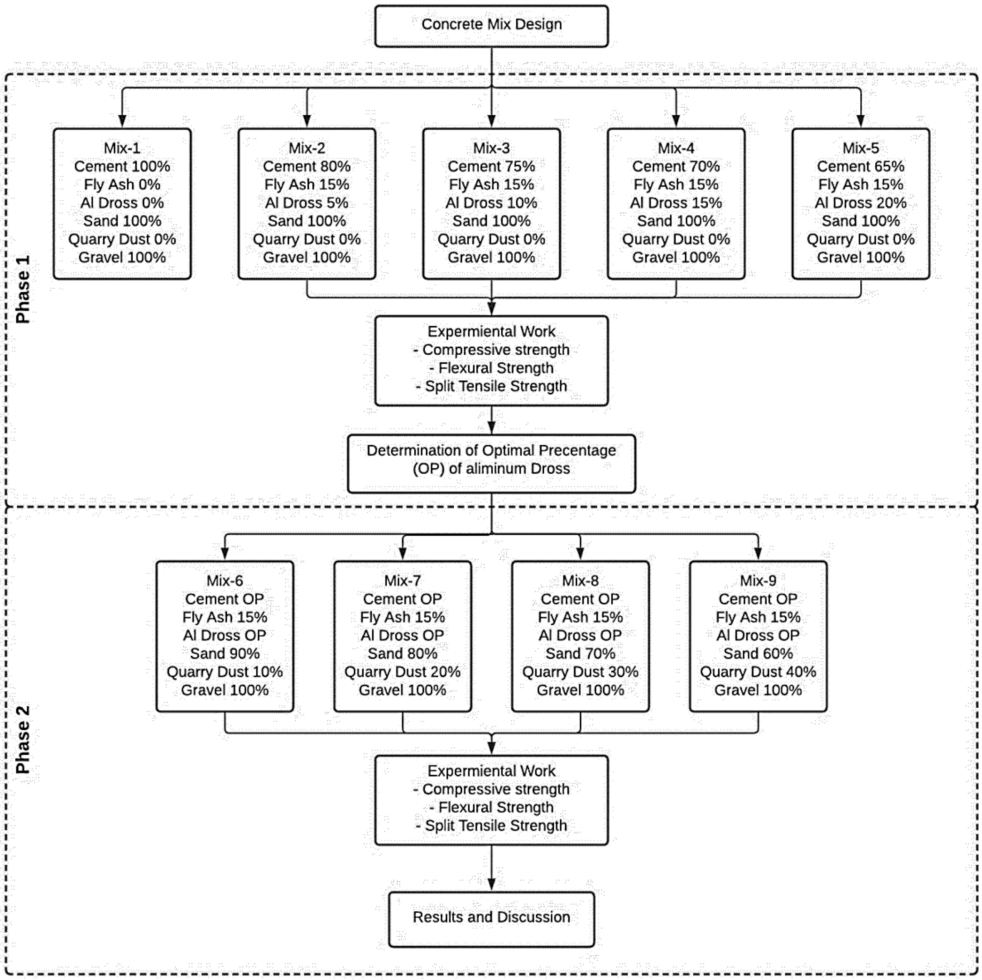


Figure 1. The experimental work design.

3.7.1. The Particle Size Distribution of Fine Aggregates

The sieve analysis test was carried out to evaluate the particle size distribution of river sand and quarry dust as per ASTM: C 136-06 [23]. Both the coefficient of uniformity (C_u) and the coefficient of

curvature (C_c) have been calculated using equations 1 and 2 to check whether the fine aggregates are well or poorly graded as defined in ASTM-D2487 [24].

$$C_u = D_{60} / D_{10} \quad (1)$$

$$C_c = D_{30}^2 / (D_{60} \times D_{10}) \quad (2)$$

where:

- C_u is the coefficient of uniformity;
- C_c is the coefficient of curvature;
- D_{10} is the passing grain diameter at 10%;
- D_{30} is the passing grain diameter at 30%; and
- D_{60} is the passing grain diameter at 60%

3.7.2. Mix Design of Concrete

In the current work, the concreter grade we aimed to accomplish was a minimum compressive strength of 30 MPa (M30) at the age of 28 days. M30 of the concrete mixtures was drawn up in accordance with the guidelines of ACI 211.1-96 [25]. The water-to-cement ratio (w/c) of 0.45 was introduced. A slump of 100 mm was designed to maintain good concrete workability. A constant amount of 15% fly ash was added to all concrete mixtures except the control mix (MIX1) in order to improve the workability and durability of concrete incorporating aluminum dross and quarry dust. The amount of aluminum dross and quarry dust in each mixture was varied. The control concrete mixture (MIX1) contained only OPC, sand, and coarse aggregate. The experimental work was carried out in two phases. In the first phase, Al dross was replaced with 5, 10, 15, and 20% cement in the MIX2, MIX3, MIX4, and MIX5 mixtures, respectively. Initially, the optimal percentage of the Al dross replacement was determined on the basis of the MIX2, MIX3, MIX4, and MIX5 compressive strength results. In the second phase, the optimum percentage of Al dross was replaced for cement in mixtures MIX6, MIX7, MIX8, and MIX9, and the quarry dust was replaced for 10, 20, 30, and 40% for river sand of their weights. The mixing of the 1 m^3 concrete proportions is explained in Table 4. The control mix is MIX1, the mixtures MIX2 to MIX5 are a concrete containing aluminum dross and fly ash only, and the mixtures MIX6 to MIX9 are a sustainable concrete containing aluminum dross, fly ash, and quarry dust.

Table 4. The mix proportions for 1 m^3 concrete.

Type	Phase	First Phase					Second Phase			
	Mix	**MIX1**	**MIX2**	**MIX3**	**MIX4**	**MIX5**	**MIX6**	**MIX7**	**MIX8**	**MIX9**
Cementitious Materials	% of cement	100	80	75	70	65	OP	OP	OP	OP
	Cement (Kg/m^3)	350	280	262.50	245	227.50	262.50	262.50	262.50	262.50
	% of fly ash	0	15	15	15	15	15	15	15	15
	Fly ash (Kg/m^3)	0	52.50	52.50	52.50	52.50	52.50	52.50	52.50	52.50
	Aluminum dross (%)	0	5	10	15	20	OP	OP	OP	OP
	Aluminum dross (Kg/m^3)	0	17.50	35	52.50	70	28	28	28	28
Fine Aggregates	% of sand	100	100	100	100	100	90	80	70	60
	Sand (Kg/m^3)	645	645	645	645	645	580.50	516	451.50	387
	% of quarry dust	0	0	0	0	0	10	20	30	40
	Quarry dust (Kg/m^3)	0	0	0	0	0	64.50	129	193.50	258
Coarse Aggregate	% of crushed granite	100	100	100	100	100	100	100	100	100
	Crushed granite (Kg/m^3)	1290	1290	1290	1290	1290	1290	1290	1290	1290
	Water (Liters)	157.50	157.50	157.50	157.50	157.50	157.50	157.50	157.50	157.50

OP = Optimal Percentage.

3.7.3. Fresh Concrete Characteristics

A slump test was carried out to measure the workability of concrete mixtures in accordance with the ASTM C 138/138M-16 [26]. A slump cone with a height of 300 mm, a base diameter of 200 mm, and an upper diameter of 100 mm was used. The slump values were calculated on the basis of the difference between the two heights of the slump cone and the fresh concrete after removal of the slump cone. Higher workability can be achieved with a slump value of more than 100 mm and medium workability with a slump value of between 50 mm and 100 mm.

3.7.4. Durability Characteristics of Concrete

The water absorption test was carried out to determine the water absorption potential of the concrete specimens. According to the guidelines of ASTM C 642-06 [27], for each mixture, concrete cubes of the size 150 mm were cured in water for 28 days. The dried cubes were weighed (W_1) and then immersed in water for 24 h, while the wet cubes were also weighed (W_2). The absorption of the water was calculated that use Equation (3).

$$\text{Water absorption (\%)} = (W_2 - W_1)/W_1 - 100 \quad (3)$$

3.7.5. Hardened Concrete Characteristics

The compressive strength test was carried out in compliance with the guidelines of BS EN 12390-3 [28]. The cured cubes of the size 150 mm of each concrete mixture were placed at the center of the universal test machine with a capacity of 5000 kN and provided a uniform loading up to the crushing of the cubes. The flexural strength test was conducted in compliance with the guidelines of BS EN 12390-5 [28].

The flexural strength machine with a capacity of 100 kN was introduced with the specimen beams with a length of 500 mm, a width of 100 mm, and a height of two points of load on the beams. The split tensile strength was conducted on concrete cylinders with a length of 300 mm and a diameter of 150 mm in the compression test machine in accordance with the guidelines of BS EN 12390-6 [28]. Three strength tests were conducted on 7-and 28-day water-cured specimens.

4. Results and Discussion

4.1. Particle Size Distribution of Fine Aggregates

The grading classification of fine aggregates depends on the coefficient of uniformity (C_u) and the coefficient of curvature (C_c) values. In order for aggregates to be well graded, the value of (C_u) must be greater than 6, while the value of (C_c) must be between 1 and 3. Otherwise, the fine aggregates will be considered to be poorly graded, as defined in ASTM-D2487 [24]. The well-graded aggregate contains minimum voids; therefore, a minimum quantity of paste is needed to fill them. The distribution of particle size of river sand and quarry dust resulting from the sieve analysis test is shown in Figure 2. The coefficient of uniformity and the coefficient of curvature are shown in Table 5. As shown in Figure 2 and Table 5, the river sand and quarry dust have a coefficient of uniformity (C_u) of 7.35 and 6.75, with a coefficient of curvature (C_c) of 1.86 and 1.13, respectively. As a result, both river sand and quarry dust are well graded.

Table 5. Coefficients of uniformity and curvature of river sand and quarry dust.

Property	Coefficient of Uniformity (C_u)	Coefficient of Curvature (C_c)
River sand	7.35	1.86
Quarry dust	6.75	1.13

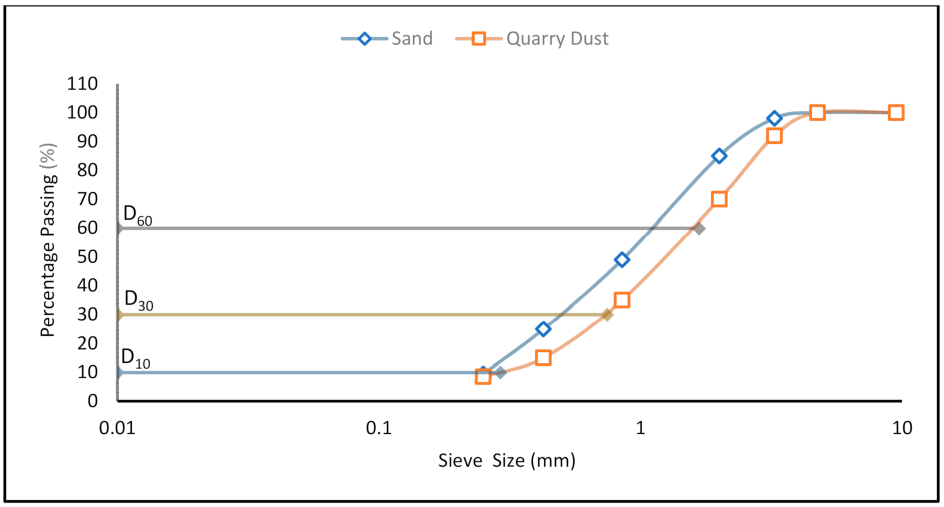


Figure 2. The particle size distribution of river sand and quarry dust.

4.2. Results of Fresh Concrete Characteristics

The workability of the various concrete mixtures was determined by performing a slump test by following instructions of ASTM C 138/138M-16 [26]. The slump values are shown in Table 6. In the present study, the concrete mix MIX3 had a higher slump value due to the replacement of 10% of Al dross and 15% of fly ash with cement.

Table 6. Slump values of concrete mixes.

Mix	MIX1	MIX2	MIX3	MIX4	MIX5	MIX6	MIX7	MIX8	MIX9
Slump value (mm)	100	100	112	90	88	109	110	94	89

In addition, the MIX7 mixture, which incorporated 10% of Al dross, 15% of fly ash, and 20% of quarry dust, also achieved a high slump value for concrete with good workability. However, with the increase in the percentages of Al dross as in the mixtures of MIX4 and MIX5, the workability decreased. At higher levels of quarry dust, such as in MIX8 and MIX9 mixtures, more voids were created, and a higher rate of water absorption was achieved, which reduced the water available for good workable concrete.

4.3. Results of Durability Characteristics of Concrete

The durability and strength of the concrete are significantly affected by the absorption of water in accordance with the guidelines of ACI 211.1-96 [25]. In other words, lower water absorption gives higher strength due to fewer voids within the concrete sample. As can be seen in Table 7 in the first phase of the experimental work, the concrete sample MIX3 containing 10% of Al dross had the lowest absorption rate of water than the control mix MIX1. However, by increasing the percentage of Al dross above 10%, the water absorption rate increased as in the MIX4 and MIX5 mixtures. This is because Al dross was found to cause internal micro-blisters in concrete samples that produce micropores in higher substitutions [10]. Similarly, the MIX7 mixture containing 10% Al dross, 15% fly ash, and 20% quarry dust reported the lowest rate of water absorption in the second phase of the experimental work. The quarry dust was found to increase the water absorption rate by more than 20% of the replacements, as found by previous research [13–15]. The fly ash incorporated into the concrete mix acted as a filler and helped to fill the capillary pore spaces. This reduces the size of the pores and the absorption of water in the concrete mixture, as observed by previous research [16,17].

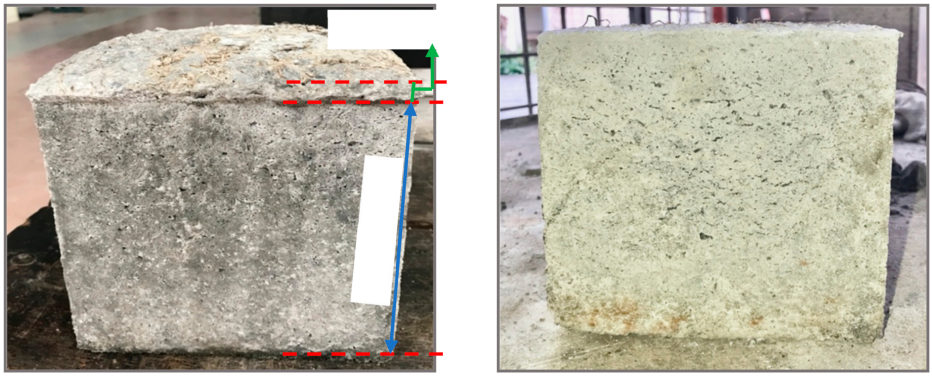
Table 7. Water absorption values of concrete mixes.

Mix	MIX1	MIX2	MIX3	MIX4	MIX5	MIX6	MIX7	MIX8	MIX9
Water absorption (%)	3.10	2.90	2.70	3.30	3.50	2.73	2.69	3.16	3.34

4.4. Results of Hardened Concrete Characteristics

4.4.1. Results of Concrete Mix Trials

From the experimental studies, a significant increase was observed in the 5% unwashed raw aluminum dross produced in the concrete mix, as shown in Figure 3a. However, the concrete mixture incorporating water-washed aluminum dross did not show a noticeable increase in volume, as shown in Figure 3b. It is, therefore, not practical to use aluminum dross in the production of concrete without pre-treatment, which is following the same observation of Pereira et al. [11].



(**a**) (**b**)

Figure 3. (**a**) Expansion of concrete mix produced at 5% replacement of untreated aluminum (Al) dross and (**b**) concrete mix produced at 5% replacement of treated Al dross.

4.4.2. Results of Compressive Strength

The compressive strength results of concrete mixes at curing periods of 7- and 28-days are shown in Figure 4. In the first phase, the concrete mix—MIX3 (10% Al dross) recorded relatively higher compressive strength compared to the concrete mix—MIX2 (5% Al dross), and relatively lesser by 0.7% compared to the control mix MIX1 (0% Al dross) at 7- and 28-days curing period. However, the concrete mixes of MIX4 (15% Al dross) and MIX5 (20% Al dross) have recorded the lowest compressive strength among all the concrete mixes in the first phase. This is related to the amount of CaO (lime) and SO_2 (silica), which are the main factors strengthening the concrete. For mix3, 10% of Al dross and 15% of fly ash compensate for the reduction of the cement in the mix, while in MIX3, the 5% of Al dross was not enough to compensate for the reduction of CaO in cement. Therefore, the optimum replacement of aluminum dross was assigned at 10%.

In the second phase of the experimental work, at 28 days, the concrete mix—MIX7 produced 10% of Al dross, 15% of fly ash, and 20% of quarry dust—showed a noticeable increase in compressive strength by 7% compared to the control mix—MIX1. On the other hand, the concrete mixes—MIX8 and MIX9 recorded 5.7% and 9.2% less than the control mix strength—MIX1. Based on the findings of the compressive strength at all ages of the concrete mixtures, the optimum levels of substitution of cement and sand were 10% of Al dross and 20% of quarry dust. It was observed that there was a steady decline in compressive strength with an increment in the Al dross percentage above 10%. This may be due to the formation of air gaps caused by aggressive reactions and excessive alumina at a higher replacement of Al dross [11], as can be seen in Figure 5. In addition, by higher replacement of quarry dust more than 20% as in the MIX8 and MIX9 mixtures, more voids were created. As a result, the demand for water increased, which had a negative impact on the compressive strength.

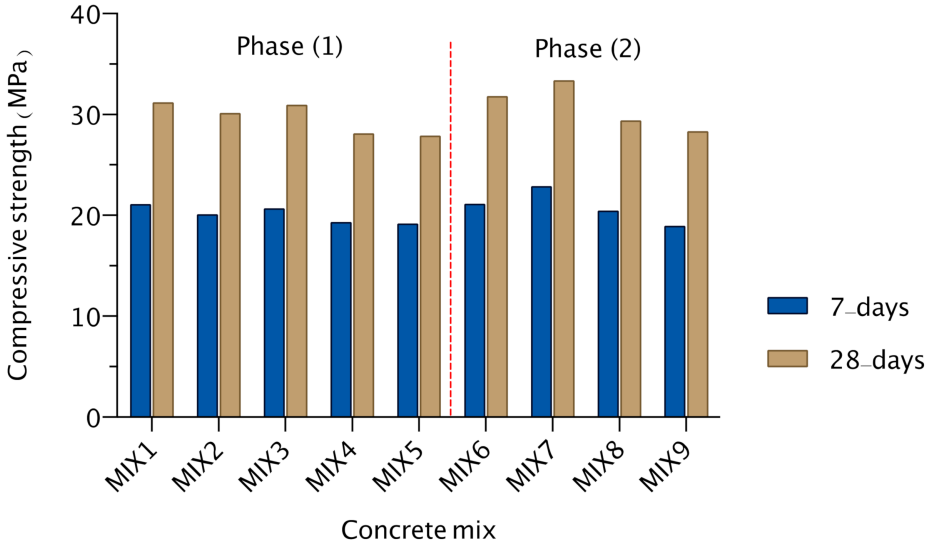


Figure 4. Compressive strength of 7- and 28-day concrete mixes.



Figure 5. Deterioration of concrete at 30% Al dross replacement.

4.4.3. Results of Flexural and Split Tensile Strengths

The average flexural strength of the concrete specimens of the control mixture was approximately 5.09 MPa and 7.23 MPa, respectively, at 7 and 28-day curing periods. The concrete mixtures—MIX2 and MIX3 with 5% and 10% aluminum dross replacement at 7.01 and 7.06 MPa, respectively, at 28 days of age. Figure 6 shows the flexural strength of concrete mixtures between 7 and 28 days of age. It was observed that the flexural strength of the mixtures—MIX4 and MIX5—was approximately 9.2 and 16.2% lower than that of the control mixture—MIX1. However, the concrete mix—MIX7 (10% Al dross, 15% fly ash, and 20% quarry dust) achieved maximum strength. The flexural strength of the concrete specimen-MIX7 was 5.21 and 7.51 MPa, respectively, at 7 and 28 days of age, indicating an increase in strength over time. This is due to the increase in the hydration rate of concrete. In addition to the 20% replacement of quarry dust, the flexural strength was reduced as in mixtures-MIX8 and MIX9.

The split tensile strength followed the pattern of the compressive and flexural strengths. As shown in Figure 7, in the first phase of the experiment, the tensile strength of the mixture-MIX3 was approximately 2.2 and 1.2% lower than that of the control mixture-MIX1, respectively, at 7 and 28 days of concrete age. The optimum mix—MIX7, recorded the highest tensile strength of all concrete mixtures.

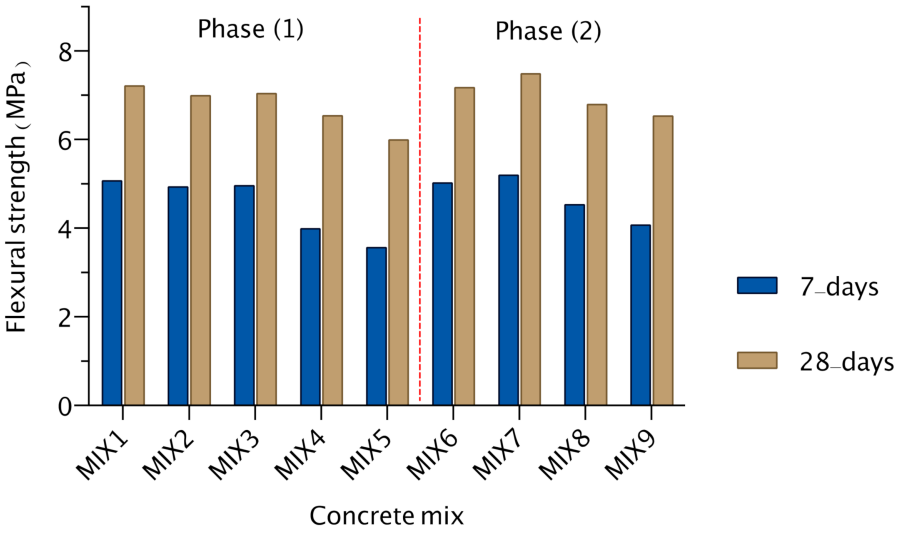


Figure 6. The flexural strength of 7-and 28-day concrete mixes.

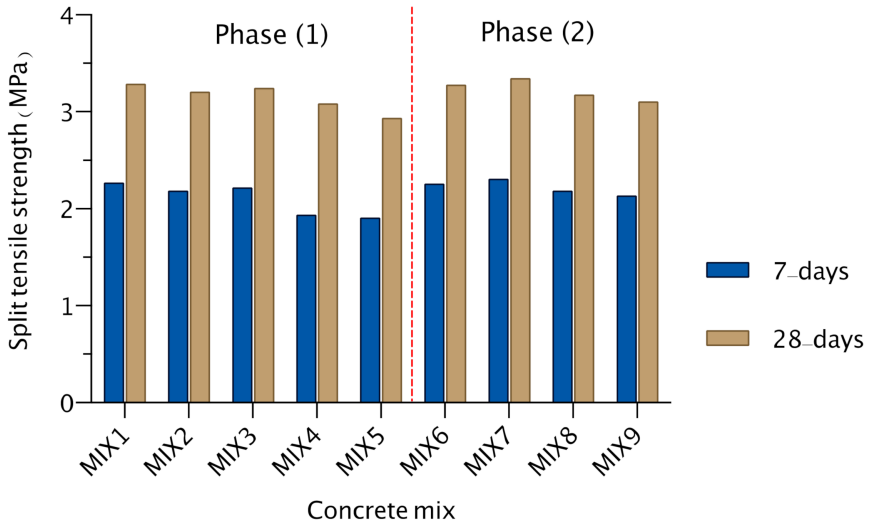


Figure 7. The split tensile strength of 7-and 28-day concrete mixes.

5. Conclusions

The present study was carried out to produce sustainable concrete by incorporating three industrial wastes, namely fly ash, aluminum dross, and quarry dust. Fly ash and aluminum dross were partially replaced with cement, and the river sand was partially replaced with quarry dust. Initially, with the constant replacement of 15% fly ash with cement, the optimum replacement of aluminum dross was determined without the use of quarry dust in concrete mixtures and, later, the optimum percentage of quarry dust was determined by the incorporation of the blended cement (cement + 15% fly ash + optimal Al dross).

The mechanical properties and durability of the mixture of three wastes were investigated. A concrete was produced by incorporating 45% waste (15% fly ash, 10% aluminum dross, and 20% quarry dust). The following conclusions are outlined based on the experimental investigation conducted on the concrete mixtures.

- The particle size distribution obtained from the sieve analysis test showed that both river sand and quarry dust are well-graded aggregates. This indicates that minimum voids are created and, as a result, improved the water absorption and strength of the concrete mix.

- The concrete mixtures—MIX3 (15% fly ash and 10% aluminum dross) and MIX7 (15% fly ash, 10% aluminum dross, and 20% quarry dust) have recorded an increase in slump values by 12 and 10% compared to the control mix, indicated a good workable concrete.
- It was observed that the concrete specimen deteriorated when aluminum dross was replaced by cement by 30%.
- The water absorption rate of the nine mixtures was investigated. The results showed that the rate of water absorption of concrete mixtures increased by increasing the replacement percentage of aluminum dross and quarry dust by more than 10 and 20%, respectively. MIX7 showed the lowest absorption rate by approximately 13.2% lower than that of the control mix—MIX1.
- By increasing the percentage of aluminum dross and quarry dust by more than 10% and 20%, the strengths decreased. At 28 days of the curing period, the concrete mixture—MIX7 showed an increase in the compressive, flexural, and split tensile strength by 7, 3.8, and 1.8%, respectively, compared to the control mixture—MIX1.
- According to the results of the present study, the optimum mixture was found to be a concrete mixture—MIX7 (fly ash-15%, aluminum dross-10%, and quarry dust-20%).

Overall, the use of industrial waste such as fly ash, aluminum dross, and quarry dust in concrete production can make a significant contribution to environmental sustainability and to the conservation of natural resources. For future research, the microstructure of concrete could be investigated for further understanding of the relationship between the chemical changes and the concrete strength due to the presence of aluminum dross in the concrete mix.

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