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Utilization of Aluminum Dross as a Cement Replacement Material for Sustainable Concrete Development

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ABSTRACT

The recovery of aluminum from aluminum dross waste involves intensive cost and energy. Therefore, there is a need for its utilization as an engineering material by using it as a filler material in concrete production. The cement industry is battling numerous difficulties due to the shortage of raw materials and sustainability issues related to the emission of CO_2 into the atmosphere. On this basis, the present study aims to utilize aluminum dross as a replacement material for cement to develop sustainable concrete. In this study, the results of control concrete samples were compared to the results of concrete samples containing aluminum dross by 5%, 10%, and 15% by weight of cement. The mechanical and chemical analysis of the M40 grade concrete employing aluminum dross as a replacement material in cement was analyzed. It was noticed that the best percentage of aluminum dross was 10%, providing better results compared with conventional concrete. It recorded the highest strength of 41.3MPa. Thermogravimetric analysis was conducted in which weight loss, decomposition of hydration compounds, and percentage of calcium hydroxide from concrete were determined. Scanning electron microscopy analysis showed that the density of concrete increased owing to the presence of ettringite needles and calcium silicate hydrate in the matrix. Moreover, the toxicity analysis revealed that the ammonia content and the leachability of trace elements from the concrete were both low and within

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acceptable ranges. The findings indicate that aluminum dross has positive results as an additional cementitious material in concrete to overcome environmental problems related to dross management and reduce cement utilization, producing more sustainable concrete.

Keywords: Aluminum dross, industrial waste, sustainability, toxicity analysis

INTRODUCTION

Concrete is the most widely used substance on Earth that will continue to be in demand for a very long time. However, concrete is also one of the most powerful factors that contribute to global warming. Annually, the estimated amount of cement needed is around 50% to produce almost 11 billion tonnes of concrete (Imbabi et al., 2012). Cement manufacture makes concrete a heavy pollutant as it emits CO_2 into the atmosphere, leading to global warming (Bakhtyar et al., 2017). Naqi and Jang (2019) reported that around 90% of CO_2 is emitted from one ton of cement manufactured. Annually, cement production is estimated at 3.5 billion tonnes, releasing almost 3 billion tonnes of CO_2. Hence, between five and seven percent of all CO_2 emissions are caused by the cement industry.

Subsequently, an alternative must be initiated to replace cement partially or fully with ecologically cementitious materials to control the construction costs and mitigate the environmental impact. In the last few decades, waste production and the exhaustion of natural sources have become issues in the industrial sector (Mahinroosta & Allahverdi, 2018). For the protection of the environment, the substitution of alternative building materials in concrete technology is a must. Due to the rise of worldwide awareness in the environmental sector, the utilization and recycling of industrial wastes in concrete technology have been increasing rapidly daily.

Recent studies found that various pozzolanic materials are combined with cement to produce prime concrete for its strength and durability. According to Walker and Pavía (2011), pozzolan is specifically described as a material containing a silicious or silicious and aluminous content that chemically reacts with calcium hydroxide to form hydration compounds when mixed with water. Generally, pozzolanic materials are derived from industrial waste, including rice husk ash, quarry dust, silica fume, fly ash, rice husk ash, slag cement, aluminum dross, and other materials (Elseknidy et al., 2020). Waste materials such as cement replacements have become gradually treasured in concrete production. In short, industrial waste can be replaced as a building material in concrete production.

Industrial waste, such as aluminum dross (AD), is a remarkably responsive pozzolanic material that can be added to concrete production. Remarkably, alumina and silica are the main elements of aluminum dross, which are necessary for pozzolan characteristics (Nirmale & Bhusare, 2018). Utilizing aluminum dross in concrete is a good option as it increases the workability of the concrete.

Several studies have examined the potential usage of aluminum dross in the construction industry. Panditharadhya et al. (2018) used secondary aluminum dross as a binding agent in concrete production. Initially, cement was substituted with 5%, 10%, 15%, and 20% of aluminum dross by weight of the cement, and the ideal dosage was determined to be 15%. This research observed that aluminum dross accelerated the final setting time, making it fit for hot weather conditions. The mechanical properties also improved with the optimum dosage of aluminum dross in concrete.

Soós et al. (2017) utilized aluminum dross as asphalt filler. Typically, manufacturers only used limestone as a filler in the asphalt industry. There were three trial mixes in this study: (1) Mix A (100% dross), (2) Mix B (100% limestone), and (3) Mix C (50% dross). Based on this work, Mix C, which contained 50% dross, was determined to be a potential percentage in asphalt filler as this ratio of dross produces a stiffer mix in all temperature ranges.

Dirisu et al. (2021) investigated the manufacture of silicate composites containing aluminum dross to construct ceilings. Thirty percent aluminum dross by weight of cement was found to be a suitable thermal insulator needed in building ceilings as it achieved the highest specific heat capacity with a low value of heat flux. Aluminum dross also improved its mechanical properties due to the presence of ferrous and non-ferrous metals, which developed stronger bonds in the composite.

Over the years, there was a generation of waste called dross in aluminum refining industries. Meshram and Singh (2018) stated that this kind of waste has leachable salts like KCl, so the direct disposal of such waste would be an environment issue. Most aluminum dross is disposed of in landfill sites. The disposal of aluminum dross into landfills will cause the toxic metal ions to leach into the ground, contaminating the groundwater (Zauzi et al., 2016). Sultana et al. (2013) reported that approximately 1.5% to 2.5% of dross is generated for each metric ton of molten aluminum. Consequently, recycling the aluminum dross and developing an engineered product can be practical ways to reduce sustainability problems.

MATERIALS AND METHOD

Material Properties

The American Society for Testing and Materials (ASTM) procedures were used throughout the study to denote the properties of materials.

For this study, cement pastes were prepared by consuming grade CEM I 52.5N ordinary Portland cement (OPC) according to BS EN 196-1 (2005). This cement grade, which contained a specific gravity of 3.20 and a bulk density of 1440 kg/m^3, is equivalent to ASTM Type 1 cement.

X-Ray Fluorescence, EDX 1400, determined the quantitative measurement of chemical oxide compositions in cement and aluminum dross. The metal oxide and chemical oxide composition of the cement and aluminum dross are presented in Table 1. Portland cement had a lower specific gravity than aluminum dross, yet the difference between the two was not significant due to the denser elements in aluminum dross, like aluminum and magnesium.

Ordinary Portland Cement (OPC) has a variety of proportions. The main constituents of cement are calcium oxide, silica, aluminum oxide, and iron oxide. Each element plays a different role in concrete development. For instance, calcium oxide (CaO), known as lime, is the major ingredient in cement manufacturing. Lime imparts strength and soundness to the cement. Kandhan and Karunakaran (2021) reported that up to 25% of lime replacement in cement can enhance the compressive strength of concrete at an early age**.** On the other hand, the second largest element in cement is silica (SiO_2). Silica strengthens concrete by making it denser via increasing dry density and lessening porosity (Pattinaja & Tjahjani, 2015). Furthermore, aluminum oxide (Al_2O_3) acts as the cement's basis, accelerating the cement's hydration reaction. Al_2O_3 is a nano-sized particle that serves as the filler material in the concrete matrix, influencing the microstructural properties of cement to become denser, resulting in decreased porosity and increased strength (Zhou et al., 2019; Meddah et al., 2020). Additionally, iron oxide (Fe_2O_3) gives color to concrete specimens. Iron oxide pigments meet the standard provided by the ASTM C 979 (American Society of Testing Materials c-979-99, 2015).

Cenviro Sdn Bhd, Port Dickson, Negeri Sembilan provided the aluminum dross used in this project. The sample was in fine powder form, blackish in color, with small aluminum pieces. The bulk density and specific gravity of aluminum dross were 774 kg/m^3 and 3.40, respectively. Referring to Table 1, the average particle size distribution of aluminum dross

Table 1
Chemical oxide composition of cement and aluminum dross by XRF analysis

Metal oxide	Chemical oxide Composition (%)	
	Ordinary Portland Cement	Aluminum Dross
Aluminum oxide (Al_2O_3)	6	82.8
Calcium oxide (CaO)	62.5	2.8
Iron (III) oxide (Fe_2O_3)	3.9	2.6
Magnesium oxide (MgO)	0.9	0.5
Silicon dioxide (SiO_2)	22.5	6.4
Zinc oxide (ZnO)	0	0.32
Sulfur trioxide (SO_3)	1.75	0
Loss of Ignition	1.5	2.7
Others	0.95	0.88
Physical parameters		
Density (kg/m^3)	1440	774
Specific gravity	3.20	3.40
Average particle size distribution d_{50} (μm)	7.20	15.6

Note. The remaining 0.88% of aluminum dross composition is attributed to traces of TiO_2, N_2O, PbO, Br and P. TiO_2, Na_2O, K_2O, and N_2O existed in traces in the cement composition with 0.95%

is higher than cement due to the particle size where aluminum dross contains rougher particles. In concrete technology, the distribution of the particle size is crucial. The size of particles directly influences the hydration, setting, and hardening, strength, and heat of hydration (Udvardi et al., 2019).

Pretreatment of Aluminum Dross

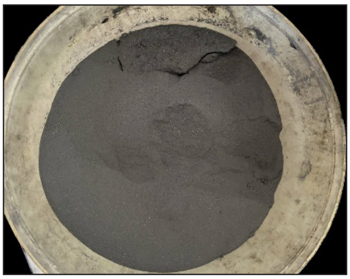


Figure 1. Aluminum dross sample

The aluminum dross was treated prior to being used in concrete production. The most effective method to remove any potential oxide generation and toxic gas formation from an aluminum dross sample is simply washing it with water (Panditharadhya et al., 2018). Before the aluminum dross was substituted in concrete, it underwent a pretreatment process by being washed in water with a solid-to-liquid ratio of 1:6. Then, it was sun-dried followed by oven-dried to eliminate water and passed through a sieve of 100 µm before being added into concrete mixture. The sample of aluminum dross is shown in Figure 1.

Both fine and coarse aggregates conforming to BS EN 12620 (2002) were used in this study. Easily reachable river sand, which has a fineness modulus 2.32 and a specific gravity of 2.65, was chosen as the fine aggregate. Crushed granite with a maximum size of 20 mm was used for coarse aggregate. The specific gravity and fineness modulus of coarse aggregate are 2.77 and 8.50, respectively.

Potable water that was free from any malignant substance and had a pH value between 6 and 8, as specified by MS EN 1008 (2010), was used in this research work. The water source was within the Construction Material Laboratory (MCL) of the Department of Civil Engineering, Universiti Putra Malaysia.

Mix Proportioning of Concrete Materials

In the present work, the concrete mixtures were constructed for M40 grade concrete to achieve a minimum compressive strength of 40 MPa at the end of the curing age of 28 days. M40 is a commercial-grade concrete used in a heavy-duty application. The substructure is one of the applications included where it is constructed under the ground of a building. The building's weight is evenly distributed throughout the substructure and the ground beneath it (Khan, 2015). According to BS EN 1990 (2002), the minimum grade of structural concrete is M20. Based on the literature review, cement has been partially replaced with aluminum dross in the concrete development with a designated compressive strength of up to 35 MPa (Mailar et al., 2016; Galat et al., 2017; Elseknidy et al., 2020; Arpitha & Praveen, 2022). Therefore, this study investigated the characteristics of M40-grade concrete made with different percentages of aluminum dross.

The ratio of water-cement (w/c) at 0.4 was implemented. The slump value was assigned at 100 mm to obtain a good workable concrete. Each trial mix had a different proportion of cement and aluminum dross. All concrete mixtures were added with the same amount of aggregates. The control concrete mixture (C1) was made without substituting any aluminum dross. The experimental work was executed with the replacement values of aluminum dross at 5,10, and 15% by weight of ordinary Portland Cement (OPC) in the C2, C3, and C4, respectively. These specimens were tested after the 7th, 21st, and 28th days of water curing age to obtain the results in three different conditions. The description of different trial mixes based on the concrete mixing of 1 m^3 concrete proportion is tabulated in Table 2.

Table 2

Concrete mix proportions of 1 m^3 *concrete*

Type	Concrete mix	C1	C2	C3	C4
Cementitious materials	% of cement	100	95	90	85
	Cement (kg)	346.0	328.7	311.4	294.1
	% of Aluminum dross	0	5	10	15
	Aluminum dross (kg)	0	17.3	34.6	51.9
Fine aggregate	% of sand	100	100	100	100
	Sand (kg)	646	646	646	646
Coarse aggregate	% of gravel	100	100	100	100
	Gravel (kg)	790	790	790	790
	Water (liters)	138	138	138	138

Fresh Concrete Properties

A slump test was performed to assess the workability of the concrete mixture, complying with the BS EN 12350-2 (2009). A slump test was done prior to casting the concrete into the molds. The slump cone, which was in the shape of a conical frustum, had a 300 mm height, 200 mm base diameter, and 100 mm upper diameter. Greater workability of concrete can be attained with slump values higher than 100 mm.

Concrete Strength Properties

In this work, the cube samples of size 100 mm × 100 mm × 100 mm were used to test the compressive strength as per the guidelines of BS EN 12390-3 (2001). The specimen was placed at the center and loaded uniformly until the cube with a capacity of 6.0kN/s failed. The concrete samples were tested on the 7th, 21st, and 28th day of curing age.

The flexural strength test was carried out on the 28th day of curing age on concrete beams with a size of 100 mm × 100 mm × 500 mm based on BS EN 12390-5 (2019). A three-point load with a capacity of 0.1kN/s was applied to the concrete beam. The machine for compression and flexural strength tests was provided in the Construction Material Laboratory (CML) at Universiti Putra Malaysia.

Concrete Durability Properties

The water absorption rate of the concrete samples was observed by using the water absorption tests. The concrete specimens of each mix design with a size of 100 mm x 100 mm x 100 mm were tested as per the provisions of ASTM C 642-06 (American Society for Testing and Materials, 1997). The samples curing for the 7th and 28th days were oven-dried for 24 hours before being weighed (W1). Then, the samples were immersed in water for 24 hours. The samples were removed from the water tank after 24 hours and dried with a clean, dry towel before being weighed (W2). Equation 1 was used to calculate the water absorption rate.

$$\text{Water absorption (\%)} = \frac{W_2 - W_1}{W_1} \times 100 \qquad [1]$$

Concrete Microstructural Analysis

This study determined the microstructure analysis through a Scanning Electron Microscope (SEM) conducted at the Material Characterization Laboratory (MCL), Universiti Putra Malaysia. The SEM images of all concrete mixes were analyzed. The morphology analysis was conducted at different magnifications from ×200 to ×40000 using SEM: JSM -5610V, JOEL. The concrete specimens were collected in a small size of 5 mm on the 28th day.

Concrete Thermogravimetric Analysis

TGA analysis was carried out to categorize the decomposition of hydration compounds in the concrete. The samples were prepared by manually grounding the concrete using an agate mortar and pestle and sieving through 75 mm (Reddy & Naqash, 2019a; Vogler et al., 2022). At the end of the 28th day of curing age, approximately 1 g of sample was stored in a closed plastic bottle from each concrete mix. The analysis was performed using TGA Mettler Toledo at the Thermal Analyzer Laboratory, Faculty of Science, Universiti Putra Malaysia. The experimental setup included a platinum top-opened crucible, an active atmospheric nitrogen gas (40 ml/min), and a heating rate of 10°C/min. Then, the samples were heated at a steady rate at a temperature range of 50°C to 1000°C.

Concrete Toxicity Analysis

The toxicity of ammonia level in aluminum dross was determined during the washing process and curing of concrete by using the salicylate method on the DR 900 colorimeter.

The samples were mixed with the reagent of ammonia salicylate and ammonia cyanurate for a sample that resulted in a dark green color with a reading of more than 50 mg/L of ammonia. Dilution of the sample was conducted.

The Toxicity Characteristic Leaching Procedure (TCLP) was employed to examine the toxic and heavy metals to determine whether aluminum dross concrete was ecologically suitable at 28 days of age of concrete. Initially, the coarse aggregates were removed from the concrete specimen, which was ground to obtain a finely powdered sample that could cross a 1.00 mm sieve. The concrete sample's leachate was produced in accordance with the US Environmental Protection Agency (US EPA). Then, the toxicity analysis of the leachate produced by the treated aluminum dross was performed. Perkin Elmer 2000DV spectrometer was used to conduct an Inductively coupled plasma optical emission spectroscopy (ICP OES) at Material Characterization Laboratory (MCL), Universiti Putra Malaysia, to examine the leachate elements from the finely powdered samples.

RESULTS AND DISCUSSION

Concrete Mix

This study incorporated aluminum dross into the concrete mixture, replacing cement. The outer layer surface of the control concrete mix, C1, was quite smooth, which offers better interaction within the matrix, as shown in Figure 2a. However, in Figures 2b, 2c, and 2d, the formation of voids was increased with the higher percentage of aluminum dross incorporation. It can be observed that 15% aluminum dross content in the concrete mix (C4) in Figure 2d showed more voids compared to the concrete mixes C2 and C3. The formation of voids could cause a decline in the concrete strength as the proportion of aluminum dross increased.

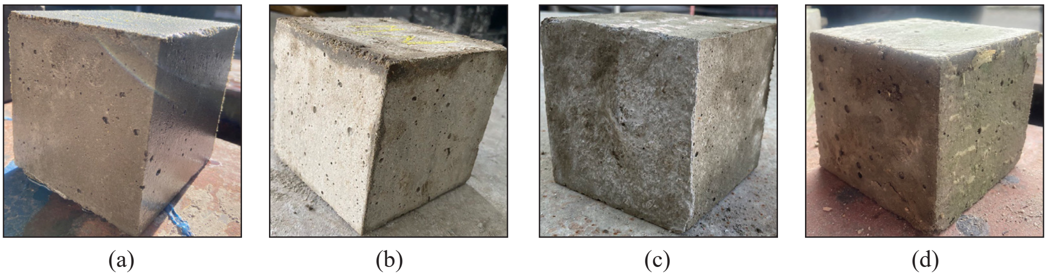

(a) (b) (c) (d)

Figure 2. (a) Concrete mix C1; (b) Concrete mix C2 (5% aluminum dross); (c) Concrete mix C3 (10% aluminum dross); and (d) Concrete mix C4 (15% aluminum dross)

Concrete Fresh Properties

From the results, the concrete mix C3 had the highest slump value with good workability because of aluminum dross at a 10% replacement value. However, the workability decreased with the increased percentage of aluminum dross in C4. The slump values are summarized in Table 3.

Table 3
Slump values of concrete mixes

Mix	C1	C2	C3	C4
Slump value (mm)	100	100	113	91

Concrete Strength Properties

Figure 3 depicts the compressive strength results for all concrete mixtures on the 7th, 21st, and 28th days. Over the curing periods, the concrete mix C3 with 10% aluminum dross had higher compressive strength compared to C2 (5% aluminum dross) and C4 (15% aluminum dross). The increase in compressive strength with age is credited to the continuous formation of hydration products (Odeyemi et al., 2021). The compressive strength of mix C3 is 41.3MPa, which has shown slightly higher strength compared to the control mix C1 at 40MPa, as a basis. Hence, the ideal dosage of aluminum dross was considered at 10%. The pozzolanic action and filler effects of aluminum dross can improve compressive strength in concrete. The higher percentage replacement of aluminum dross in concrete mix C4 lowered the compressive strength. It could be because of the formation of air voids as a result of aggressive reactions and high alumina content.

The average flexural strength of the control mixture, C1, was around 9.87MPa at the end of 28 days of curing age. The flexural strengths of concrete mixes at the 28 days are presented in Figure 4. It was observed that the concrete mixtures C2 (5% aluminum dross) and C4 (15% aluminum dross) had flexural strength approximately 6.4 and 11.3% lower than the control mixture C1. The maximum flexural strength of 10.03MPa was achieved by concrete mix C3 (10% aluminum dross) at the age of 28 days due to the presence of the fined particles of aluminum dross in concrete that can compact the gap, which can strengthen the bond between the concrete component.

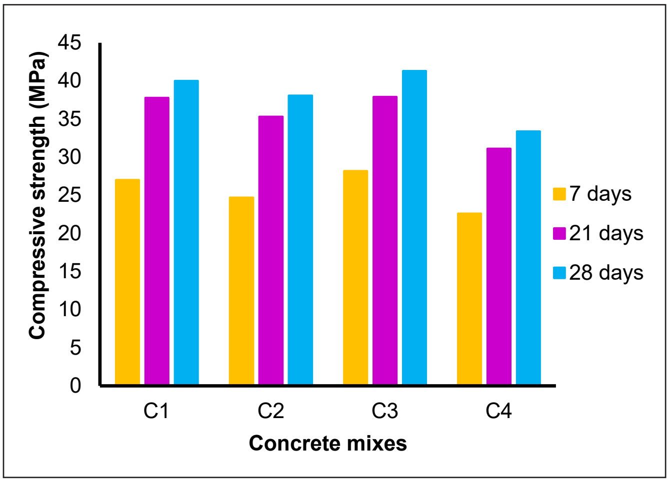


Figure 3. Compressive strength of concrete mixes at 7, 21, and 28 days

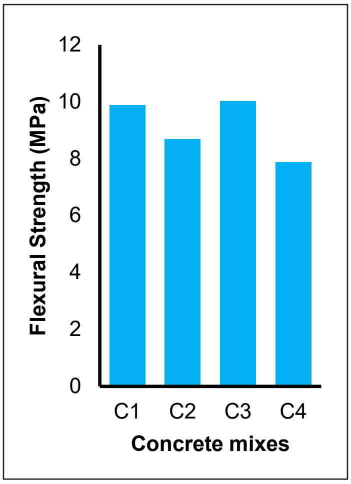


Figure 4. Flexural strength of concrete mixes at 28 days

Concrete Durability Properties

Curing is the most vital process in concrete production. It serves to avoid premature evaporation of moisture from concrete mixtures, which could reduce the strength of the resulting concrete—specifically, lower absorption results in higher strength because there are fewer voids in the concrete specimen. Hence, the hardened concrete should be submerged in water to cure. The concrete mixes were cured for the durability test for the 7th and 28th days. Figure 5 shows water absorption rates calculated using Equation 1 on days 7 and 28 of the concrete mixes. As shown in Figure 5, out of all the aluminum dross concrete mixes, C2 (5% aluminum dross) had the lowest water absorption. On the other hand, it was discovered that concrete mix C3 (10% aluminum dross) had nearly the same water absorption as concrete mix C1. The concrete mix, C4 (15% aluminum dross), absorbed more water than the control mix, C1. Javali et al.(2017) mentioned in the report that this action is because of the behavior of aluminum dross that can result in internal micro-blisters in the concrete samples that increase the number of micropores.

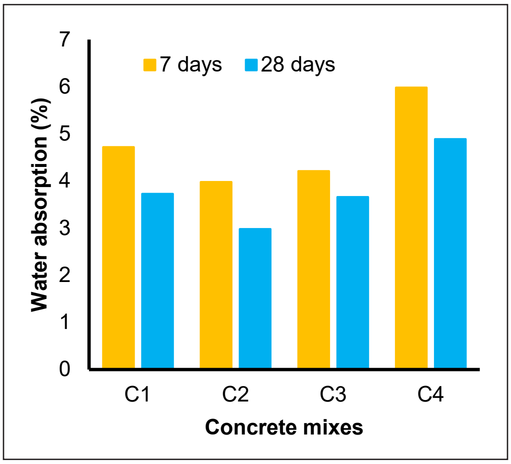
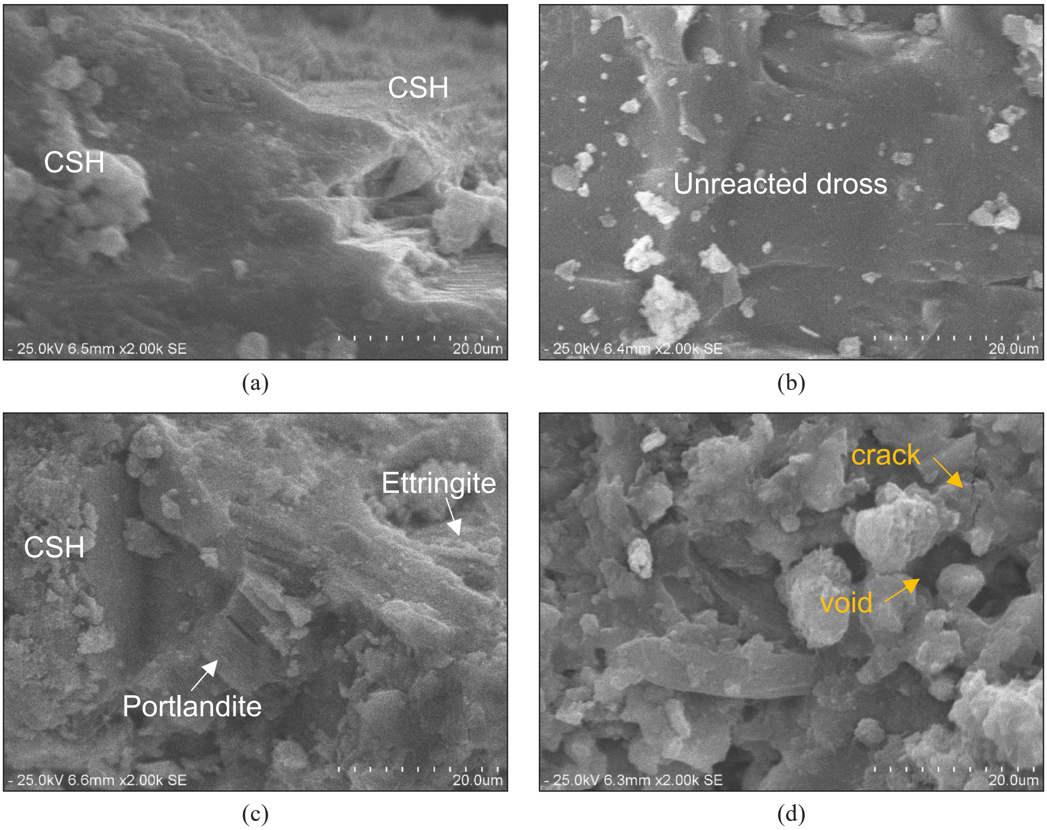


Figure 5. Water Absorption of concrete mixes at 7 and 28 days

Concrete Microstructural Analysis

Concrete microstructure evolves over time, resulting from the concrete formulation and processes involving mixing, placement, and curing. The SEM images for all concrete mixtures are illustrated in Figure 6. The main hydration product, calcium silicate hydrate (CSH), is visible in the control concrete mix, C1(Figure 6a). In Figure 6b, C2 is depicted as the asymmetrical shape of unreacted dross, where the SEM image of concrete mix. In Figure 6c of a concrete mix made by 10% aluminum dross (C3 mix), it can be observed that the formation of calcium hydroxide (also known as portlandite) results during the curing process when calcium reacts with water. The aluminum oxide content in aluminum dross chemically reacted with calcium hydroxide to produce hydration compounds (Mailar et al., 2016). The calcium monosulpho-aluminate (ettringite) can also be seen as smaller hexagonal hydrated crystals due to aluminum dross. It was seen that concrete containing aluminum dross has a less permeable surface due to the development of needles (ettringite) in voids compared to control concrete. The concrete with aluminum dross provided slightly higher strength compared to conventional concrete due to the filling activities of aluminum dross in voids. The image in Figure 6d (C4 mix) shows the presence of micro-pores within



(a) (b)

(c) (d)

Figure 6. SEM images of concrete mixes: (a) Concrete mix C1; (b) Concrete mix C2 (5% aluminum dross); (c) Concrete mix C3 (10% aluminum dross); and (d) Concrete mix C4 (15% aluminum dross)

the matrix as well as the formation of micro-cracks caused by internal blisters. The matrix becomes less compact as a result of these cracks.

Concrete Thermogravimetric Analysis

The TGA results presented in Figure 7 show the decomposition of hydration compounds in temperatures ranging from 50°C to 1000°C, and Figure 8 illustrates the weight loss of concrete mixes with respect to temperature. From Figure 7, the TG curves portray four distinct endothermic outcomes. The first effect was the evaporation of pore water from capillary pores, in the temperature range of 50°C to 100°C (Ukrainczyk et al., 2006). The second endothermic effect was subjected to the dehydration of calcium silicate hydrates and ettringite, which occurred at temperatures between 100°C and 450°C. The third effect, with peak temperature between 400°C and 500°C, was associated with the decomposition of calcium hydroxide formed during hydration, as shown in Equation 2.

$$Ca\,(OH)_2 \rightarrow CaO + H_2O \qquad [2]$$

In the final endothermic effect, the decarbonization of calcium carbonate in the hydrated compound was indicated at around 800°C, as shown in Equation 3.

$$\mathrm{CaCO_3} \rightarrow \mathrm{CaO} + \mathrm{CO_2}\ \text{(Decarbonation)} \qquad [3]$$

The weight difference between the temperature at 100°C and 600°C was used to calculate the total weight loss, which included water loss from other hydrates (Vedalakshmi et al., 2003). The amount of calcium hydroxide was calculated using Equation 4 as a percentage of the weight at 580°C (Reddy & Naqash, 2019b). Calcium hydroxide has a molecular weight of 74, and water has a molecular weight of 18.

$$\text{Calcium hydroxide} = \frac{W_{400} - W_{580}}{W_{580}} \times \frac{74}{18} \times 100 \qquad [4]$$

As shown in Figure 9, the percentage of calcium hydroxide was higher in the control mix, C1, compared to concrete mixes, C2, C3, and C4, which contained aluminum dross.

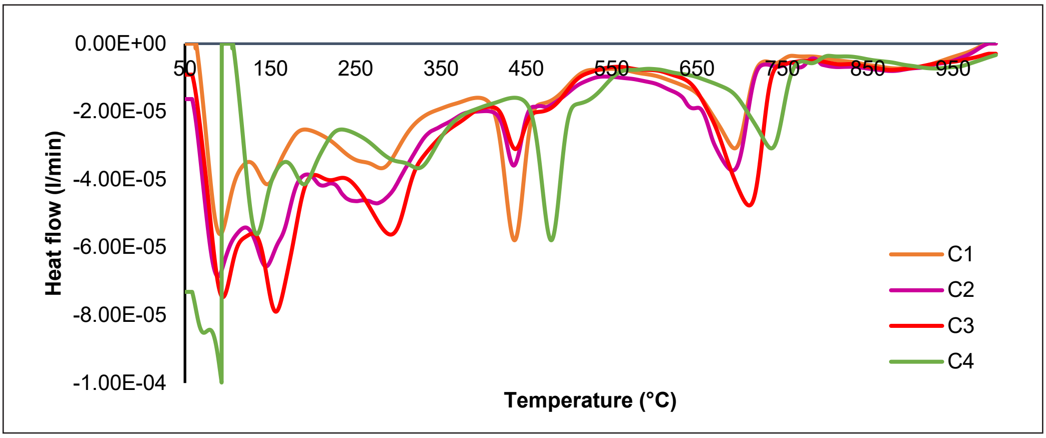


Figure 7. TG curve of concrete mixes

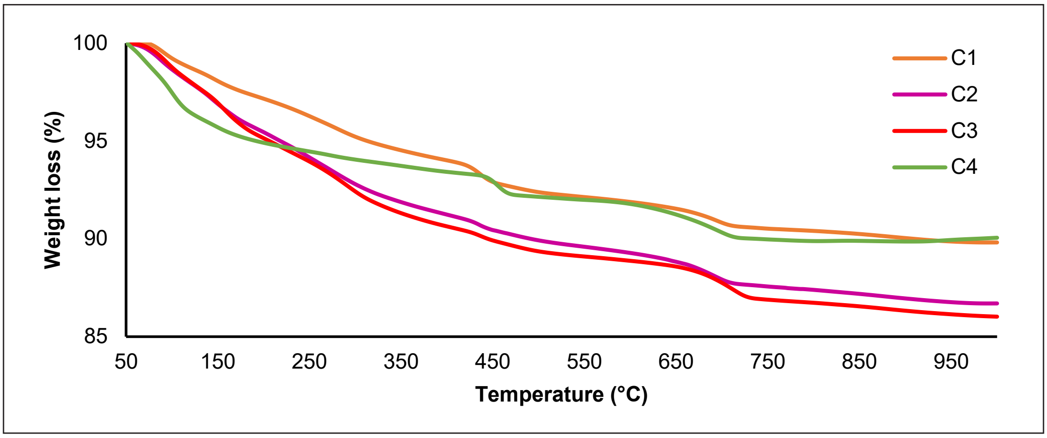


Figure 8. Percentage of weight loss of concrete mixes

In concrete mixes containing aluminum dross, calcium hydroxide was present at a lower percentage due to the pozzolanic reaction in which silicates and aluminates in aluminum dross consumed calcium hydroxide (Retgaddy & Naqash, 2019b). Reddy and Neeraja (2016) reported that aluminum dross decelerated the pozzolanic reaction with the excess calcium hydroxide produced due to the higher specific surface area of aluminum dross particles, in which high water intake is required.

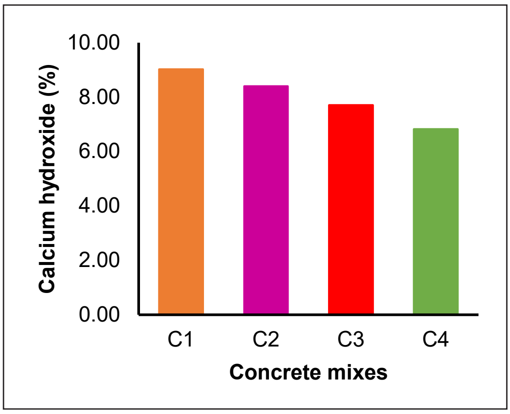


Figure 9. Percentage of calcium hydroxide of concrete mixes

Concrete Toxicity Analysis

The ammonia level tests were conducted for aluminum dross samples and concrete mixes. Ammonia levels in the concrete mixes were tested at 7 and 28 days of curing age because of the high ammonia content in aluminum dross during the washing process. During the washing process, a pungent smell from the mixture of water and aluminum dross was present, and it turned out to be ammonia gas. A high-speed mixer at 250 rpm and two times water washing were implemented during the pretreatment process to reduce the amount of ammonia in aluminum dross. Table 4 shows the ammonia level in aluminum dross before and after the treatment (water washing) process. The results shown in Table 4 showed that the ammonia content increased up to 30 ppm. As shown in Table 5, the ammonia concentration in the control concrete mixture, C1, was absent.

Meanwhile, for concrete mixtures, C2, C3 and C4 were reduced over the curing period from 7 days to 28 days and within the limits annotated by the Occupational Safety

Table 4
Concentration of ammonia in aluminum dross

Condition of sample collected	Concentration of ammonia (ppm)
Before treatment	0
After treatment	30

Table 5
Concentration of ammonia in concrete mixes

Concrete mixes	Concentration of ammonia (ppm)		Regulated limit value (ppm)
	7 days	28 days	
C1	0	0	50
C2	10	3	50
C3	13	5	50
C4	19	7	50

Note. The legalized level refers to the limit stipulated by OSHA PEL and Health Administration Permissible Exposure Limits (OSHA PEL). A higher aluminum dross incorporation value depicts higher ammonia concentration release. This correlation can be related to the morphological study of concrete. As can be observed from Figure 6d, namely the concrete mixture C4, there was a formation of microcracks and a gap between the concrete matrixes. The diffusion of ammonia gas from the concrete will render it more porous, affecting its strength (El-Aziz & Sufe, 2013).

The amount of minor to major components detected in the leachate samples of aluminum dross and concrete mixes at the end of 28 days of curing age were identified using Inductively coupled plasma optical emission spectroscopy (ICP-OES), Perkin Elmer 2000DV spectrometer. Table 6 illustrates the numerous elements found using the ICP-OES analysis at the wavelength of 90 ppm. Heavy elements in aluminum dross and concrete mixes included aluminum, arsenic, chromium, copper, nickel, and zinc. In the aluminum dross leachate sample, the concentration of the above elements (except for arsenic) was found to be within the limits prescribed by the Waste Acceptance Criteria (WAC) and the United States Environmental Protection Agency (EPA). Aluminum dross from aluminum manufacturing is recovered via a hydrometallurgical process that includes acid leaching to recover metals (Kudyba et al., 2021). Therefore, the leachate concentration in aluminum dross is higher than the leachate of concrete mixes.

It was observed that in almost all concrete mixes, including control mix C1, the heavy metal concentration was very minimal and within the limits. Concrete mix, C4, is the only concrete mix that has surpassed the WAC limit, where the concentration of arsenic and chromium is slightly higher than the regulated limit. Ordinary Portland Cement (OPC) usually has a pH of 12, which indicates high alkalinity. When OPC comes in contact with water, Concrete is highly alkaline, and when it comes into touch with water, the non-

Table 6
Toxicity analysis of aluminum dross and concrete mixes

Element	Leachate of concrete (ppm)				Leachate of aluminum dross (ppm)	Regulated limit level (ppm)	
	C1	C2	C3	C4		US Environmental Protection Agency (US EPA)	Waste Acceptance Criteria (WAC)
Aluminum	na	0.30	0.40	0.60	0.60	0.05-0.20	
Arsenic	0.20	0.32	0.43	0.56	0.62	5.00	0.50
Cadmium	0.01	0.02	0.02	0.03	bdl	1.00	0.04
Chromium	0.09	0.13	0.49	0.67	0.19	5.00	0.50
Copper	0.33	0.44	0.45	0.39	0.87	1.30	2.00
Nickel	0.09	0.11	0.12	0.1	0.13	1.00	0.40
Zinc	0.92	2.68	3.85	2.33	1.15	1.50	4.00

Note. na: not available; bdl: below the detected level
Regulated limit level imposed by USE EPA and Waste Acceptance Criteria (WAC)

volatile metals (chromium and arsenic) are released (Sumra et al., 2020; Eckbo et al., 2022). In addition, Estokova et al. (2018) reported that substituting higher waste materials in a concrete mixture also contributes to the increase of leachate in the cement matrix. Thus, the higher concentration of chromium and arsenic in concrete samples, C4, was due to the higher percentage of aluminum dross. Table 6 shows that the concentration of elements increases as the dosage of aluminum dross increases. Based on the results of the toxicity test, the increment of the metal values was below the leaching limit value, indicating that the concrete will be safe to use as construction materials.

CONCLUSION

The current study was performed to develop sustainable concrete by adding aluminum dross into the mixture. An easy aluminum dross treatment method that included washing, drying, and sieving was practical and efficient to acquire a material suitable for concrete. The mechanical and chemical behavior of aluminum dross concrete type were investigated. Within the scope of the project, many tests were performed to evaluate the properties of aluminum dross and concrete that contained aluminum dross.

The following conclusions are drawn as a result of this experimental investigation:

- The slump values for the concrete mix, C3 (10% aluminum dross), increased by 6.1% compared to the control mix, C1, which demonstrated that the concrete has good workability.
- The strength value of concrete decreases with increasing aluminum dross content. Compared to the control mix, C1, the compressive and flexural strength of concrete mix, C3, increased by 1.6% and 0.8%, respectively, at 28 days of curing age.
- A higher volume of aluminum dross incorporation depicts a higher water absorption rate of concrete. The results showed that at the end of 28 days of curing age, the concrete mix, C3, has an almost identical water absorption rate of approximately 0.9% lower than the control mix, C1.
- From SEM analysis, a higher amount of aluminum dross can cause the formation of micropores and micro-cracks, which will affect the strength of the concrete. Aluminum dross in concrete decreased the porous microstructure and improved the formation of hydrates. The concrete mix, C3, has the formation of calcium silicate hydrate (CSH), calcium hydroxide, and ettringite in the matrix due to the presence of aluminum dross.
- From the TGA analysis, aluminum dross concrete was found to have less calcium hydroxide due to a pozzolanic reaction with respect to the control concrete mixture. It was observed that the concrete mix, C3, has a 7.9% lower percentage of calcium hydroxide compared to the control concrete mix, C1, which makes it more stable.

- The toxicity analysis showed that the ammonia concentration in concrete decreased with curing age. In the concrete mixture, C3 has a 44.4% ammonia concentration reduction. Though the ammonia gas is still entrapped in the concrete, the strength and durability properties of the concrete would not significantly be affected. Additionally, it was observed that the concrete leachate contained no toxic materials, and the heavy metals content was within the regulated level.
- Based on the findings, it was determined that 10% was the optimum replacement value of aluminum dross in the concrete mixture. This percentage of substitution will not harm the properties of concrete, and the compressive strength will remain close to that of normal concrete.

Hence, it can be concluded that aluminum dross, as an industrial waste, can be a potential candidate to be substituted in cement for concrete production. The replacement is feasible considering enhanced properties as well as conserving environmental sustainability. For future research, various curing methods could be investigated to examine the impact on the mechanical and chemical properties of aluminum dross concrete.

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