The Use of Aluminum Waste for Concrete Production

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Abstract

Aluminum wastes (AW) have been used to produce concrete samples used for this work. Tests on the setting times, compressive and flexural strengths were conducted at replacement levels of 5, 10, 20, 30 and 40 % by weight of cement. The results showed that AW can be used as a retarder and thus, a good material for hot weather concreting. Optimum replacement values for the compressive and flexural strengths are at 10 % replacement and the statistical models developed on them are significant.

Keywords: Aluminum waste; setting times; pozzolanic activity; compressive strength; flexural strength; statistical parameters

1. Introduction

Aluminum dross is a mixture of free metal and nonmetal substances (e.g., aluminum oxide and salts). Aluminum nitrides and carbides may also be present, as well as metal oxides derived from the molten alloy (Manfredi et al. 1997). Drosses may be classified by means of their metal content and drosses with a high metal content (white, or wet, dross that is rich in free metal) typically occurs when scrap is remelted with salts in an open–hearth furnace. This black, or dry, dross is usually granular with a high metal content in the coarse fraction and chiefly oxides and salt in the fines. The possibility for non-waste utilization of aluminum dross and converting it into commercially useful products was investigated by Lucheve et al. (2005). Lack of comprehensive information on the characteristics of by-products is a major barrier to increased use of these materials.

There is also a need to develop technologies to cost-effectively convert various wastes into usable feedstock and thus, new technologies that would minimize or eliminate the formation of dross and salt cake are encouraged. Minimization of dross and salt cake formation and the development of new uses for wastes and byproducts should be the primary focus. The first can be accomplished by developing new melting processes that eliminate or minimize the formation of these wastes and, the development of economical technologies for turning aluminum waste such as red mud into usable feedstock for other processes that could eliminate this environmental problem.

Valuable aluminum metal, oxides, salts, and other materials have been wasted because of the lack of viable processing technologies to convert this material to useful products (Ramesh 1999). Therefore, this research work is on the development of a technology to divert the salt cake into valuable feedstock materials for concrete works.

2. Materials

The aluminum waste (AW) used for this study was obtained from an aluminum extrusion company (ALEX), in Inyishi, Imo State, Nigeria. The wastes are irregular in shape, black in colour and contain lumps and small particles of aluminum produced by burning aluminum scraps (raw material) in a furnace at about 1900°C. The total waste produced per day is approximately 18 tonnes. Before using the waste with concrete it was ground and sieved using sieve size 150µm. The cement used was Eagle cement, a brand of ordinary Portland cement and conforms to BS 12 (1978). The physical and chemical properties of the AW and OPC are given in Tables 1. and 2. Table 3. shows the sieve results for AW and fine aggregate. The fine aggregate used was river sand with a specific gravity of 2.62, and a bulk density of 1710 kg/m³. The coarse aggregate has a maximum aggregate size of 20 mm, specific gravity of 2.68, bulk density of 2681 kg/m³ and an average impact value of 7.1 %. Both fine and coarse aggregates fall in zone 2 in the classification chart in accordance with BS 882. The water used was a potable drinking water.

The laboratory work was in two phases: i) in the fresh and ii) hardened conditions.

i) In the fresh condition

Tests were carried out on the pozzolanic activity
index (PAI) and setting times of the AW-cement paste. The PAI was determined as per ASTM C311-77, and is defined as the ratio of the compressive strength at 28 days of the test specimen, expressed in percentage. The test was carried out using 0 % AW as the control specimen and 35 % of AW mixed with ordinary Portland cement as the pozzolanic specimen. Setting times were performed in accordance with BS 12: Part 2: Clause 7 (1978) and on the six pozzolanic mixes.

ii) In the hardened condition

Tests to determine compressive and flexural strengths were carried out in this study using the mix proportions in Table 4. The mixtures were proportioned for a cement content of 290 kg/m³, fine aggregate content of 766 kg/m³, coarse aggregate content of 1199 kg/m³, and water-cement ratio of 0.40. Concrete mixtures with six levels of AW replacement, ranging from 5 to 40 %, and control mixtures with no AW were investigated to determine their effects on compressive and flexural strengths. The mixtures were labeled AWC-0, AWC-5, AWC-10, AWC-20, AWC-30 and AWC-40, with different AW replacement percentages represented by the final digits in the label.

For the compressive and flexural strength tests, a total of ninety specimens were cast using cube moulds of 150 mm and beams measuring 100 x 600 mm respectively. They were cured for 3, 7, 28, 60 and 90 days respectively. At the end of the curing period, three samples from each were loaded to failure and the average readings recorded.

A three-point bend configuration with load applied at the centre point of the span was used for the beams and the modulus of rupture evaluated using

\[ \sigma = \frac{pl}{bd^2}. \]

### 3. Results and Discussions

Tables 1. and 2. show the physical and chemical composition of AW. The total percentage of SiO₂ + Al₂O₃ + Fe₂O₃ is 72.8 %, which is greater than the minimum (70%) specified in ASTM C – 618. The setting times of AW/OPC paste are important for practical applications of the material. This was determined using the Vicat method (BS 1881 1970) and is shown in Fig.1. The setting times increased as percentage of AW increased. AW is a latent hydraulic material and contains approximately 57 % of silicates. It needs more water for consistency and when added to cement triggers off a pozzolanic reaction with the excess Ca (OH)₂ produced during the cement hydration. Thus, AW defers the hydration of the paste and extends the setting time. This shows that AW can be used as a retarder and thus, is good material for hot weather concreting.

Fig.2. shows the compressive strength of AW/OPC concrete mixes with different AW contents and with different periods of water curing. Fig.2.a shows the effect of AW replacement on compressive strength. A decreasing trend is observed as the percentage of AW increases. Fig.2.b on the other hand shows the effect of curing on compressive strength. An increasing trend in the strength of AW/OPC concrete as the period of curing increases is indicated. As the age of curing increases, the difference in strength between...
the control mix (% AW) and the mixes for 5, 10 and 15% replacement are reduced. This process of strength development is expected to continue with curing time until completion of hydration of cement-AW mixture (Elinwa and Mahmood 2002). The flexural strength has a similar behaviour to the compressive strength. As the replacement level increases, the flexural strength decreases (Fig.3).

Statistical analysis on the compressive and the flexural strengths (Tables 5., 6., 7. and 8: Balanced ANOVA and Regression), show that the replacement levels, age and the interaction between the replacement levels and age are statistically significant at the 1% level.

Fig.1. Setting Times of Aluminum Waste

Fig.2. Compressive Strength of AW-Concrete

Fig.3. Flexural Strength of AW-Concrete

Fig.4. Residual Versus Fitted Values (Compressive Strength)
levels and age are significant respectively (Younger 1985). The regression equations are given as:

\[ f_C = 13.0 - 2.58 \text{AW} + 5.28 \text{Age} \]

with a standard deviation of 2.381 and a correlation coefficient \( r^2 \) of 93.2%, for the compressive strength and:

\[ f_f = 3.24 - 0.729 \text{AW} + 1.68 \text{Age} \]

with a standard deviation of 0.7214 and the correlation coefficient \( r^2 \) is 93.4% for the flexural strength respectively.

Table 9. is the derived relationship between the compressive strengths at different ages with the flexural. The standard deviation (s) varies between 0.5067 to 2.578 and the correlation factor from 85.7% to 97.2%. An analysis of the intercept \( (\beta_0) \) and slope \( (\beta_1) \) shows a high correlation of 96.3% with a standard deviation of 0.4778. This confirms the adequacy of the model.

To further examine how well the obtained models fit the data used, the residual and normality plots were drawn for both the compressive and flexural strengths of the mortar cubes (Figs.5.-8.) As can be seen, there are few large residuals (Field 2002) and hence, limited apparent outliers (Razak and Wong 2004). These confirm that there are no trends to show that the models are inappropriate.

4. Conclusions

Based on the results of the present investigation the following conclusions can be drawn:

i. AW has pozzolanic values and retards the setting times of concrete and, thus could be beneficial for hot-weather concreting.

ii. Replacement levels of 5 %, 10 %, and 15 % can be used to achieve good quality concrete.

iii. Statistical analyses of the compressive and flexural strengths show that the w/c, mix and the interactions of the w/c and mix are significant.

iv. The compressive strength is related to the flexural strength as: \( f_c = a + bf_f \); where, a and b are constants.

v. The intercept \( (\beta_0) \) and slope \( (\beta_1) \) are strongly correlated.

vi. The statistical models developed in this work provide excellent predictions for the compressive and flexural strengths of aluminum waste mortars.

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