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Research paper

Mechanical and durability aspects of concrete incorporating secondary aluminium slag

M. Satish Reddy *, D. Neeraja

School of Civil and Chemical Engineering, VIT University, Vellore, Tamilnadu, India

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Abstract

The environmental impact can be minimised by making use of many industrial wastes in a sustainable manner. Recycling and reutilisation of industrial waste and by-products is of paramount importance in cement and concrete industry. In view of rapid infrastructure growth, there is an emerging need for development of cementitious materials or fillers either to replace cement or fine aggregate for stable growth. One of the industrial wastes is secondary aluminium dross. In this paper, an attempt has been made to study the mechanical and durability aspects of concrete incorporated with secondary aluminium dross. Cement has been partially replaced by secondary aluminium dross in different proportions to study the mechanical and durability aspects. Various properties such as compressive strength, split tensile strength, flexural strength, sorptivity, water absorption, rapid chloride penetration have been studied for the usefulness of secondary aluminium dross as construction material. It is observed that up to 15% replacement of cement by secondary aluminium dross, the responses are comparable with the conventional concrete. Studies have also been carried out by adding other supplementary cementitious materials such as fly ash and silica fume in various proportions along with secondary aluminium dross and found the improved mechanical and durability properties. From the overall study, it can be concluded that the concrete incorporated with secondary aluminium dross can be used for making paver blocks, refractory bricks and for normal concrete strength applications.

Keywords: Secondary aluminium slag; Industrial waste; Compressive strength; Flexural strength; Split tensile strength; Durability

1. Introduction

With the rapid increase of population, the type and quantity of waste generation from industries, factories, companies, and housing sector have increased significantly. The waste material can be broadly categorised into two types, namely, biodegradable and non-biodegradable. Most of non-biodegradable or non-decaying waste materials will not decay or degrade and will remain in the environment for several years. The non-decaying waste materials or non-biodegradable waste materials cause waste disposal problems, thereby contributing to the environmental issues. However, the environmental impact can be minimised by making use of many wastes in a sustainable manner. One of the main themes of sustainability include reduce, reuse and recycle waste. Fig. 1 presents the triple bottom line concept applicable to any industry for longer sustainability keeping in view of environmental aspects, energy conservation, profit and other considerations [1].

Recycling and reutilisation of industrial waste and by-products is a subject of great importance today in cement and concrete technology also. Traditional industrial by-products used in cement and concrete manufacture include fly ash, granulated blast furnace slags, silica fume etc. Similarly, aluminium refining industries generate different solid wastes. Disposal and recycling of dross produced during aluminium melting is a worldwide issue. Majority of dross is being disposed off in landfill sites, which is likely to result in leaching of toxic metal ions into groundwater causing serious pollution problems [2]. When secondary aluminium dross contacts with water, it is observed that it emits less amounts of harmful/toxic gases. The gases include NH_3, CH_4, PH_3, H_2, H_2S, etc. [2]. It is mentioned that recycling aluminium uses about 5% of the energy required to produce aluminium from bauxite which is significant. Recycling results in significant cost savings over the production of primary new aluminium even when the costs of collection, separation and recycling are taken into

* Corresponding author. School of Civil and Chemical Engineering, VIT University, Vellore, India. Fax: 91-416-2243092.

E-mail address: 13phd0169@gmail.com (M. Satish Reddy).

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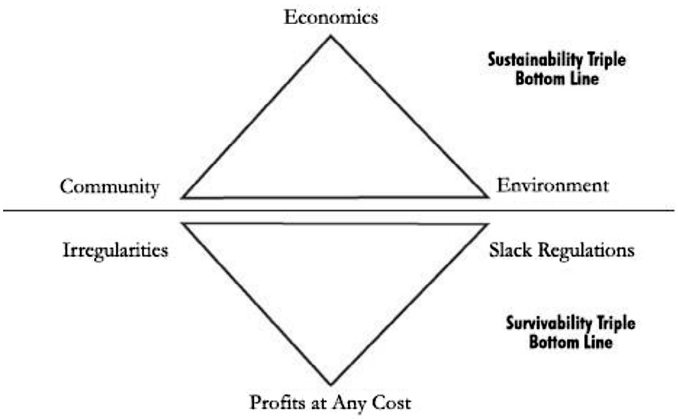


Fig. 1. Typical sustainability concept.

consideration. Considering all the factors, it appears that if the dross could be used as an engineered product, most of the sustainability issues can be addressed.

Petavratzi and Wilson [3] used aluminium dross as filler in production of non-aerated concrete, concrete bricks and concrete roof tiles. Ewais et al. [4] carried out investigations towards manufacture of calcium aluminate cement by using aluminium sludge and aluminium slag (dross) wastes as a source of CaO and Al_2O_3, respectively with some addition of alumina. Elinwa and Mbadike [5] used aluminium waste for concrete production by replacing the cement in different percentages. It was found from their experiments that the compressive and flexural strengths of concrete with 10–15% replacement of cement by aluminium waste are comparable with control concrete. It was also found that the concrete made with aluminium waste retards setting times of concrete, which is beneficial for hot weather concrete conditions. Adeosun et al. [6] evaluated the mechanical properties of polypropylene (PP) by adding aluminium dross in different proportions for particle size range between 53 µm and 150 µm. It was found that the ultimate tensile strength improved by 68% (at 15 wt% Al-dross addition), density increased by 54% (at 50 wt% Al-dross addition), and water absorption by 500% (at 8 wt% Al-dross addition) compared to conventional PP. Interestingly, the impact resistance of the composite was found to be the same (68J) as that of conventional PP at 15 wt% Al dross. Kazjonovs and Korjakins [7] produced expanded light weight aggregate by using aluminium scrap and municipal solid waste container glass. Adeosun et al. [8] studied the physio-mechanical behaviour of brick made up of aluminium dross and bentonite in different proportions and found that 106 µm particle size brick can serve as acid refractory due to its properties. Ozerkan et al. [9] evaluated the mechanical and corrosion properties of aluminium dross incorporated concrete. From their study, it was suggested that aluminium dross can be used as an ingredient in the range of certain limits to improve expanded concrete/mortar and to improve the corrosion resistivity of concrete/mortar.

It is mentioned in the open source that in India, the production of dross from various sectors is about 120,000 tons. Effective utilisation of this dross will result significantly in

1 reduction of environmental impact
2 reduction of cost of concrete
3 reduction of carbon print

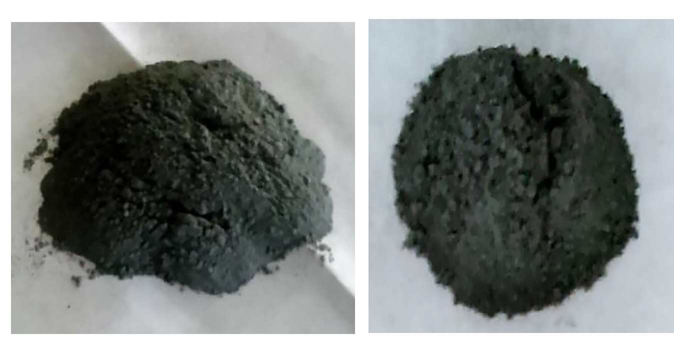
The studies carried out on concrete incorporated with secondary aluminium dross for possible utilisation as construction/building material are observed to be scanty [10–14]. In the present study, mechanical and durability properties of concrete incorporated with secondary aluminium dross and other supplementary cementitious materials such as fly ash and silica fume are investigated for possible utilisation in construction sector.

2. Experimental studies

For the present investigation, the sample of secondary aluminium dross is obtained from M/s VakkalImpex (P) Ltd, Hindupur, Andhra Pradesh, India. The wastes are irregular in shape, black in colour and contain lumps and small particles of aluminium produced by burning aluminium scraps (raw material) in a furnace at about 1900 °C. Before using the waste in concrete it was ground and sieved using sieve size of 90 µm. The collected samples were treated with water. Local sand with size of around 400 µm was used as fine aggregate which conforms to Zone II. The specific gravity of sand is 2.7 and bulking of sand is 4. Fineness modulus of fine aggregate is 3.12. The size of coarse aggregate is 20 mm. The specific gravity and fineness modulus of coarse aggregate are 2.8 and 8.47 respectively. The chemical composition of secondary aluminium dross after water wash treatment and cement obtained through XRF analysis are given in Table 1. Fig. 2 shows the typical aluminium dross sample.

Table 1
Composition of secondary aluminium dross/slag and cement.

Chemical composition	OPC	Secondary aluminium dross
Al_2O_3 (%)	5.7	87.2
SiO_2 (%)	18.3	2.7
P_2O_5 (%)	–	0.57
SO_3 (%)	4.3	1.37
Cl^- (%)	0.2	2.2
CaO (%)	65.3	2.0
TiO_2 (%)	0.5	2.0



(a) Untreated secondary aluminium dross **(b) Treated secondary aluminium dross**

Fig. 2. Typical aluminium dross.

Table 2
Properties of fly ash.

Chemical properties		Physical properties	
Constituents	Percentage (%)	Description	Value
SiO_2	60.48	Specific gravity	2.50
Al_2O_3	28.15		
Fe_2O_3	4.52	Colour	Dark grey
CaO	1.71		
K_2O	1.41		
MgO	0.47		
Na_2O	0.14		
L.O.I	1.59		

The physical properties of Ordinary Portland cement (OPC) are given below,

- Grade – 53 OPC
- Specific gravity – 3.3
- Particle size range – 35 µm–7.9 µm
- Normal consistency – 34%
- Initial setting time – 40 min
- Final setting time – 320 min
- Compressive strength:
  - 3-day strength – 30 MPa
    - 7-day strength – 37 MPa
    - 28-day strength – 58 MPa

Fly ash is obtained from Nellore Thermal Plant, Nellore, Andhra Pradesh, India. The properties of fly ash are mentioned in Table 2.

The properties of silica fume are presented in Table 3.

In the present study, it is proposed to use secondary aluminium dross in various percentages of cement by weight. The percentages include 5%, 10%, 15%, 20% and 30%. Fig. 3 presents the normal consistency obtained for various percentages of secondary aluminium dross.

From Fig. 3, it can be noted that the normal consistency is 34% for 15% replacement of cement by dross and it is 40% for 30% replacement. The percentage of water to be added to the mix is greater for larger replacements. The setting times of secondary aluminium dross (ASD) and OPC paste are very important for practical applications. In hot weather concreting, the water present in the conventional concrete evaporates at a faster rate, thereby accelerating the initial and final setting times. Since the concrete produced using aluminium dross wastes retards the initial setting times, it will be beneficial under hot weather concreting conditions. The aluminium dross causes a delay in setting time of concrete or cement due to (i) deceleration of hydration process and (ii) adsorption of nuclei of calcium hydroxide.

Table 3
Properties of silica fume.

Chemical properties		Physical properties	
Constituents	Percentage (%)	Description	Value
SiO_2	85	Specific gravity	2.6
Al_2O_3	0.28	Colour	Pale white
Fe_2O_3	0.58		
CaO	0.27		
K_2O	0.49		
MgO	0.25		
Na_2O	0.02		
L.O.I	4.4		

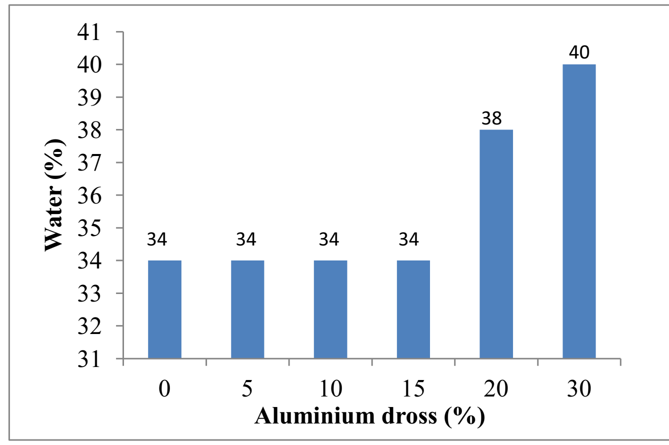


Fig. 3. Variation of normal consistency with replacement of cement by dross.

Figs. 4 and 5 show the variation of initial setting time and final setting time with percentage of ASD. From Fig. 4, it can be noted that the initial setting is increasing with the increase of percentage of dross and final setting time decreases with the increase of percentage of dross.

The increase in initial setting time can be related to the amount of silicates present in ASD. Since the nanoparticles of secondary aluminium dross have higher surface area, particles absorb significant amount of liquid. It needs more water for consistency and when added to cement reduces the pozzolanic reaction with the excess $Ca(OH)_2$ produced during the cement hydration. Hence, ASD defers the hydration of the paste and extends the setting time. This indicates that ASD can be used as a retarder and thus is a good material for hot weather concreting.

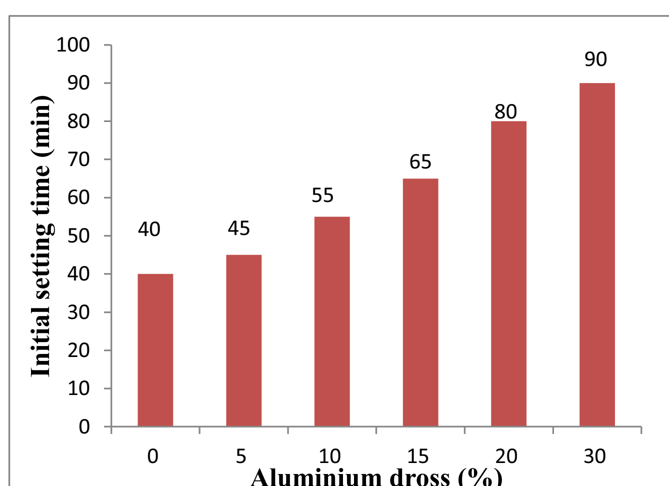


Fig. 4. Variation of initial setting time with dross.

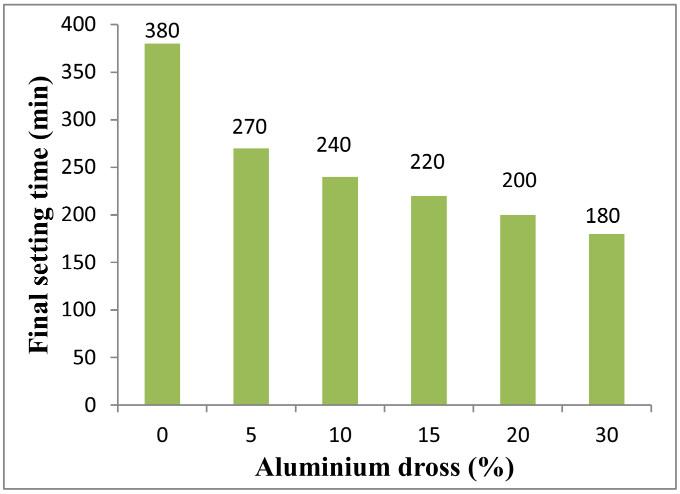


Fig. 5. Variation of final setting time with dross.

Table 4
Soundness of cement with different replacements of aluminium dross.

Mix	Initial reading (mm)	Final reading (mm)	Soundness (mm)
ASD-0	9	11	2
ASD-5	7	9	2
ASD-10	9	12	3
ASD-15	11	15	4
ASD-20	8	12	4
ASD-30	15	20	5

Soundness values for various combinations were obtained by using Le Chatelier apparatus. Table 4 presents the soundness values obtained for different combinations. From Table 4, it can be noted that soundness values are increasing with the increase of replacement levels of cement by dross. The physical meaning of soundness value is the expansion nature of concrete/cement mix. The concrete incorporated with secondary aluminium dross is found to expand high for larger replacements.

The control concrete mixture include only OPC, fine aggregate, coarse aggregate with water to cement ratio of 0.47, named as ASD-0. The remaining mixtures had varying secondary dross contents of 5%, 10%, 15%, 20% and 30% by weight of OPC and named as ASD-5, ASD-10, ASD-15, ASD-20 and ASD-30 respectively. For all the mixtures, the total quantity of cementitious material and slump value is kept constant. In order to obtain the slump value, the additional water was added gradually to the mixture which resulted in increased water to cementitious ratio (W/CM) from 0.47 to 0.55. For ASD-5, the W/CM ratio is 0.47 and 0.48, 0.50, 0.52 and 0.55 for ASD-10, ASD-15, ASD-20 and ASD-30 respectively.

The mix proportion arrived at for control concrete is 1:1.45:2.71 (Cement:Fine aggregate:Coarse aggregate) for the target compressive strength of about 30 MPa. For other mixes, extra water has been added to achieve the required slump. The size of the specimens for compressive strength is 150 × 150 × 150 mm and for split tensile strength is 150 × 300 mm. Cubes and cylinders were tested at the ages of 03, 07, 14, 28, 60 and 90 days. The size of the specimen for evaluation of flexural strength is 500 × 100 × 100 mm. Fig. 6 shows typical cast specimens. The specimens were de-moulded after 1 day and cured in a water tank at ambient temperature for 3 days to 90 days. The expansion of cube specimen is shown in Fig. 7. This is observed for higher replacement of cement by dross. The expansion is due to formation of more voids in the concrete. The air content of freshly mixed concrete incorporated with secondary aluminium dross was determined by pressure method as per the procedures outlined in ASTM C231 [15].

Fig. 6. Typical cast specimens.

The % of air content obtained for various mixes are 1.9 (ASD-0), 2.2 (ASD-5), 2.5 (ASD-10), 2.6 (ASD-15), 2.8 (ASD-20), 3.2 (ASD-30) respectively. The % of air content is increasing with the replacement level of ASD and is significant for larger replacements.

Table 5 shows the variation of compressive strength of dross incorporated concrete. From Table 5, it can be noted that the compressive strength is decreasing with the increase of % replacement of cement by dross. A general observation is that for a particular mix, the strength is increasing with age. The three day strength is about 40–50% of the 28 day strength and

Fig. 7. Expansion of cube specimen.

Table 5
Variation of compressive strength for various replacements.

Mix	Compressive strength, MPa				
	3 days	7 days	28 days	60 days	90 days
ASD-0	15.54	21.65	32.21	34.78	37.54
ASD-5	14.65	20.98	30.43	33.54	36.43
ASD-10	13.87	19.87	28.54	31.76	34.98
ASD-15	12.76	18.49	27.12	29.98	34.01
ASD-20	12.01	18.01	26.75	29.43	33.67
ASD-30	11.23	16.46	22.67	24.87	26.75

Table 7
Variation of flexural strength for various replacements.

Mix	Flexural strength, MPa				
	3 days	7 days	28 days	60 days	90 days
ASD-0	3.62	5.06	7.23	8.31	9.01
ASD-5	3.32	4.68	6.89	7.93	8.29
ASD-10	3.21	4.29	6.23	7.32	7.98
ASD-15	2.94	3.92	5.76	6.78	7.45
ASD-20	2.78	3.87	5.43	6.35	6.87
ASD-30	2.65	3.29	5.01	5.17	6.45

60–70% of the 28 day strength is obtained for 7 days. The % increase in strength for 60 days is about 10% compared to the 28 day strength and at 90 days, the strength increased is about 15% compared to the 28 day strength. Up to 15% replacement of cement by dross, % decrease in the compressive strength is comparable with control concrete (i.e., 10–15%) beyond which the decrease in strength is significant. For 30% replacement of cement by ASD, the % decrease in strength at 28 days is about 30% compared to control concrete. Even some specimens were broken during handling itself for the case of 30% replacement of cement by ASD. The reduction in compressive strength can be related to air content of the mix. The more the air content the less is the observed strength. Fig. 8 shows the graphical variation of compressive strength at a glance.

Table 6 presents the variation of split tensile strength for various replacements of cement by secondary aluminium dross. The variation of split tensile strength is similar to compressive strength. As observed in the case of compressive strength, split

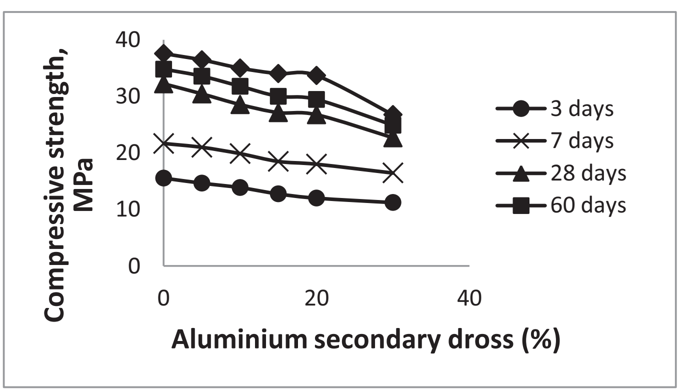


Fig. 8. Variation of compressive strength with % replacement levels of ASD.

Table 6
Variation of split tensile strength for various replacements.

Mix	Split tensile strength, MPa				
	3 days	7 days	28 days	60 days	90 days
ASD-0	1.82	2.23	3.27	3.61	3.82
ASD-5	1.63	2.06	3.12	3.45	3.61
ASD-10	1.53	1.96	2.93	3.31	3.37
ASD-15	1.43	1.92	2.78	3.13	3.21
ASD-20	1.37	1.76	2.71	2.98	3.14
ASD-30	1.19	1.51	2.32	2.46	2.63

tensile strength in general increases with age. For instance, the split tensile strength for a typical ASD-0 at 28 days is 3.27 MPa and at 60 days, the value is 3.61 which is about 10% higher than the 28 day strength. The value at 90 days is 3.82, which is about 18% higher compared to the 28 day strength. With the increase of the % of ASD, the values are decreasing and significantly less for larger replacements i.e. for ASD-30. The % decrease is about 30% compared to control concrete. The reason for reduction in strength is due to more air content in the mix for larger replacements.

Table 7 presents the variation of flexural strength for various replacements of cement by secondary aluminium dross. The variation of flexural strength is similar to compressive strength and split tensile strength. As observed in the case of compressive strength and split tensile strength, flexural strength in general increases with age. For instance, the flexural strength for a typical ASD -0 at 28 days is 7.23 MPa and at 60 days, the value is 8.31 which is about 10% higher than the 28 day strength. The value at 90 days is 9.01 MPa, which is about 22% higher compared to the 28 day strength. With the increase of the % of ASD, the values are decreasing and significantly less for larger replacements i.e. for ASD-30. The % decrease is about 30% compared to control concrete, which is attributed to more air content in the mix.

From the above investigations, it can be concluded that up to 15% replacement of cement by ASD, mechanical performance is comparable with control concrete. In the present study, it is also proposed to use other industrial wastes/by-products such as fly ash and silica fume (SF) which are cementitious in nature to enhance the mechanical and durability properties of aluminium dross incorporated concrete. Silica fume has been added in 5, 10 and 15% of cement and fly ash has been added in 10, 20 and 30% of cement. The percentage replacement of cement by dross is 5, 10 and 15%. Tables 8 and 9 present the compressive strength for various mixes of ASD, cement and SF or fly ash for 3 days, 7 days, 20 days, 60 days and 90 days respectively. It can be observed from Tables 7 and 8 that due to the addition of SF, there is a significant increase in strength. The compressive strength obtained for the mix with 15% ASD + 70% cement + 15% SF is comparable to control concrete.

Similarly, the compressive strength obtained for the mix with 15% ASD + 55% cement + 30% fly ash is comparable to control concrete. Based on the requirement and intended purpose and also the availability of materials, the appropriate mix can be chosen.

Table 8
Variation of compressive strength for different replacements of cement by ASD and SF.

ASD %	Cement (%)	SF	Compressive strength, MPa				
			3 days	7 days	28 days	60 days	90 days
0	100	0	15.54	21.65	32.21	34.78	37.54
5	95	0	14.65	20.98	30.43	33.54	36.43
10	90	0	13.87	19.87	28.54	31.76	34.98
15	85	0	12.76	18.49	27.12	29.98	34.01
20	80	0	12.01	18.01	26.75	29.43	33.67
5	90	5	14.95	21.98	31.33	34.64	36.89
	85	10	15.65	22.87	32.87	35.75	38.98
	80	15	16.23	23,76	33.98	36.24	39.97
10	85	5	14.23	20.76	29.54	32.34	35.76
	80	10	14.89	21.92	30.64	33.92	36.62
	75	15	15.78	22.94	32.65	34.29	38.01
15	80	5	13.53	19.21	29.45	32.72	35.12
	75	10	14.01	19.96	30.76	33.87	35.94
	70	15	14.86	20.96	31.89	34.23	36.23

Table 9
Variation for compressive strength of different replacements of cement by ASD and fly ash.

ASD %	Cement (%)	Fly ash	Compressive strength, MPa				
			3 days	7 days	28 days	60 days	90 days
0	100	0	15.54	21.65	32.21	34.78	37.54
5	95	0	14.65	20.98	30.43	33.54	36.43
10	90	0	13.87	19.87	28.54	31.76	34.98
15	85	0	12.76	18.49	27.12	29.98	34.01
20	80	0	12.01	18.01	26.75	29.43	33.67
5	85	10	14.75	21.32	31.01	34.34	36.32
	75	20	15.15	22.57	32.17	35.15	38.21
	65	30	16.03	23.16	33.12	36.13	39.54
10	80	10	14.01	20.14	29.02	32.13	35.14
	70	20	14.29	21.13	30.12	33.43	36.12
	60	30	15.18	22.41	32.12	34.01	37.21
15	75	10	13.01	18.92	28.76	32.13	34.10
	65	20	13.65	19.53	29.876	33.02	35.32
	55	30	14.23	20.12	31.31	33.87	35.98

3. Durability tests

To study the durability, cylinder with size of 100 mm × 200 mm is used to study the durability of concrete such as Rapid Chloride Penetration Test, Water Sorptivity Test and Water Absorption test. Durability studies were carried out for selected mixes.

In Rapid Chloride Penetration Test, the charge passed is a measure of the electrical conductance of the concrete during the period of the test, about 6 hr was recorded. The current is recorded for every 30 min interval and following the trapezoidal rule the below equation is used to calculate the total charge passed over the test specimen.

$$Q = 900(I_0 + 2I_{30} + 2I_{60} + \ldots + I_{330} + I_{360}) \quad (1)$$

where Q = charge passed in coulombs, I_0, I_{30}, I_{60}, . . ., I_{330}, I_{360} = current in amperes at 0, 30, 60, . . ., 330, 360 min.

Table 10 presents the chloride ion penetrability based on charge passed as per ASTM C1202 [16].

Fig. 9 shows the typical test setup for RCPT.

Table 10
Chloride ion penetrability based on charge passed.

Charge passed (coulombs)	Chloride ion penetrability
>4000	High
2000–4000	Moderate
1000–2000	Low
100–1000	Very low
<100	Negligible

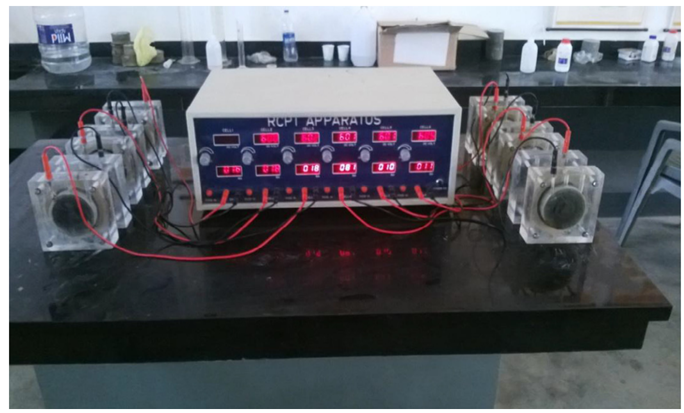


Fig. 9. Typical RCPT test setup.

After 28 days, 100 mm × 200 mm cylinders were cut into slices of 50 mm thick using concrete cutting machine to conduct durability tests. The rapid chloride penetration test is carried out as per ASTM C1202 test (2001). A water-saturated, 50 mm thick, 100 mm diameter concrete specimen is subjected to 60 V DC voltage for 6 hr. One reservoir contains 3.0% NaCl solution and the other reservoir contains 0.3 M NaOH solution. The total charge passed is determined and this is used to rate the concrete by ranging the ingress of chloride ions.

Table 11 shows that the chloride ion penetrability on control concrete is 2350 coulombs and it is increasing with increase of % of ASD. The increase of chloride ion penetrability is due to increase in air content with the % increase of ASD. The improvement of chloride ion penetrability can be clearly observed with the increase of % addition of either silica fume or fly ash. The improvement is due to filling the voids and additional formation of CSH.

Sorptivity measures the rate of penetration of water into the pores of concrete by capillary suction. The quantity of penetrated water during the time period from 30 to 60 min was determined from the weight difference of the specimens. The absorption, I, was calculated as the change in mass divided by the product of the cross-sectional area of the test specimen (a) and the density of water(d) in accordance with the ASTM C1585 Standard [17] as

$$I = m_t/(a \times d) \quad (2)$$

where I = the absorption, m_t = the change in specimen mass in grams, at time t, a = the exposed area of the specimen, in mm^2, d = the density of the water in g/mm^3.

Sorptivity test was performed in accordance with ASTM C1585 [17] on the standard test specimen, 100 mm diameter

Table 11
Results of RCPT for several mixes.

ASD (%)	Cement + SF combination		Charge passed, coulombs (average) Cement + SF + ASD	Penetrability class (ASTM C1202)	Cement + fly ash combination		Charge passed, coulombs Cement + Fly ash + ASD	Penetrability class (ASTM C1202)
	Cement (%)	SF (%)			Cement (%)	Fly ash (%)		
0	100	0	2350	Moderate	100	0	2350	Moderate
5	95	0	2455	Moderate	95	0	2455	Moderate
10	90	0	2679	Moderate	90	0	2679	Moderate
15	85	0	3241	Moderate	85	0	3241	Moderate
5	90	5	2165	Moderate	85	10	2234	Moderate
	85	10	2093	Moderate	75	20	1954	Low
	80	15	1865	Low	65	30	1665	Low
10	85	5	2463	Moderate	80	10	2513	Moderate
	80	10	2265	Moderate	70	20	2210	Moderate
	75	15	2074	Moderate	60	30	1934	Low
15	80	5	3142	Moderate	70	10	3156	Moderate
	75	10	2876	Moderate	60	20	2743	Moderate
	70	15	2654	Moderate	50	30	2376	Moderate

disc with a length of 50 mm to measure the rate of penetration of water into the pores of concrete by capillary suction. Table 12 presents the sorptivity values obtained for various mixes. From Table 12, it can be noted that the concrete incorporated with large amount of ASD absorbs more water and when it is mixed with other cementitious materials such as silica fume and fly ash, water absorption is reduced.

The water absorption test is carried out at the age of 28 days as per standard procedure ASTM C642 [18]. The water absorption test is carried out at the age of 28 days according to standard procedure ASTM C642 [18] on the standard test specimen, 100 mm diameter disc with a length of 50 mm to measure the percentage of water absorption of the concrete. The average water absorption percentages are presented in Table 12. From Table 12, it can be noted that the % of water absorption for control concrete is 7.2 and it increases with increase of ASD%. The value of water absorption for 15% replacement of cement by ASD is 11.2% which is about 50% more than the control concrete. Due to the addition of other cementitious materials such as silica fume and fly ash, the significant improvement is observed for the case of 15% addition of silica fume and 30% addition of fly ash along with various replacement levels of ASD.

4. Summary and concluding remarks

Extensive experimental investigations were carried out on concrete incorporated with aluminium secondary dross (ASD) for possible utilisation in construction sector. Aluminium secondary dross has been replaced by cement in various percentages. From the studies, it is observed that in up to 15% replacement of ASD, there is no significant decrease in mechanical and durability properties. Further, to enhance mechanical and durability properties of concrete incorporated secondary aluminium dross, other supplementary cementation materials such as silica fume and fly ash have been added in various proportions. The main observations from the study are presented below:

- When aluminium slag is used in the range of certain limits, increasing aluminium dross content accelerates the hardening which could be due to higher surface area.

Table 12
Sorptivity and water absorption for concrete mixes incorporated with ASD, silica fume and fly ash.

ASD (%)	Cement + SF combination		Sorptivity index, $mm/min^{1/2}$ (Average)	Water absorption (%) (Average)	Cement + fly ash combination		Sorptivity index, $mm/min^{1/2}$ (Average)	Water absorption (%) (Average)
	Cement (%)	SF (%)			Cement (%)	Fly ash (%)		
0	100	0	0.0255	7.2	100	0	0.0255	7.2
5	95	0	0.0264	8.1	95	0	0.0264	8.1
10	90	0	0.0275	9.4	90	0	0.0275	9.4
15	85	0	0.0291	11.2	85	0	0.0291	11.2
5	90	5	0.0258	7.5	85	10	0.0256	7.4
	85	10	0.0252	6.8	75	20	0.0250	6.6
	80	15	0.0245	6.2	65	30	0.0242	5.9
10	85	5	0.0271	9.1	80	10	0.0268	8.9
	80	10	0.0267	8.5	70	20	0.0262	8.3
	75	15	0.0260	7.4	60	30	0.0256	7.1
15	80	5	0.0286	10.8	70	10	0.0282	10.5
	75	10	0.0281	10.1	60	20	0.0276	9.6
	70	15	0.0273	8.9	50	30	0.0268	8.5

- With the incorporation of aluminium dross as a retarding admixture in concrete, there was a considerable reduction in the workability for the same water to binder (w/b) ratio as that of concrete mix without admixture. This is because the water available in the system for maintaining workability decreases due to absorption of water over the high specific surface area of aluminium dross, thereby decreasing the consistency as well. Hot weather increases the hydration of cement, resulting in a faster setting of concrete, which denotes the reduced availability of time for placing and finishing of concrete. With the use of aluminium dross, a delay in the setting of concrete is observed.
- The compressive strength, split tensile strength, and flexural strength decrease with increasing aluminium dross content. As the replacement percentage of aluminium dross is increased, more entrapped air occurs and this causes a negative effect on strength.
- RCPT, sorptivity and permeability are found to increase with the percentage levels of ASD and are significant for larger replacements.
- Aluminium dross retards the initial setting and accelerates the final setting of concrete.
- When aluminium slag is used in the range of certain limits along with the mineral admixture such as silica fume and fly ash, improved mechanical and durability properties were observed.
- At 30% replacement level, concrete cubes were broken.
- Expansion of concrete increases with increase of aluminium dross percentage by weight of cement. Hence, aluminium dross acts as an expanding agent; it can be used in the manufacturing of building subfloors, blocks and pre-moulded panels.
- The expansion of the concrete can be reduced by using other admixtures like silica fume and fly ash.

The concrete incorporated with aluminium secondary dross up to specified limits will result in (i) economy, (ii) ecological benefits, (iii) reduction of carbon footprint, and (iv) achievement of sustainability.

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