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Strength characteristics of concrete produced with aluminium dross as partial replacement for portland pozzolana cement

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Abstract

Innovative method of waste disposal can be through utilizing them in concrete production as a filler material or pozzolana. Aluminium dross is a by-product obtained from the aluminium re-smelting process. Aluminium waste is processed in rotary kilns to recover the metal and residual salt cake is sent to landfills. The present study investigates the utilization of aluminium dross as a binder in producing the concrete. It is observed that the initial setting time of the cement paste increases and final setting time decreases with varying percentages of Aluminium dross replacement. This property makes it suitable for hot weather conditions. It was replaced in 5, 10, 15 and 20% of the weight of the cement and optimum dosage was found to be 15 %. The mechanical properties like Compression strength, split tensile strength, flexural strength and water absorption of the M40 grade concrete were determined. It is observed that up to 15% replacement of cement by aluminium dross is giving better results comparable with the conventional concrete. Results show that the Aluminium dross can be replaced as supplementary cementitious material in concrete with no compromise in the mechanical properties of the concrete produced with Portland Pozzolana Cement.

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Keywords: aluminium dross, supplementary cementitious material, mechanical properties, portland pozzolana cement, industrial waste.

1. Introduction

There is a significant rise in the quantity of waste generation from various types of factories, industrial sectors, companies, and construction sector, because of rapid growth in population of the world. Biodegradable and non-biodegradable wastes are getting produced into the environment at a very faster rate. The waste materials which will not decay or degrade and will affect the ecology for maximum period are the non-biodegradable wastes. Such non-decaying wastes or non-biodegradable waste materials cause the disposal issues, thereby leading to the ecological imbalance. Sustainable use of these wastes in other useful ways can reduce the environmental impact to maximum extent. Reduce, reuse and recycle the waste materials are the main 3 R’s in the field of sustainability (Nilmani and Makhijani, 2006).

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In the construction of concrete structures and pavements, many researches are taking place to give space to the utilization of industrial waste products by recycling them and reutilizing them effectively. Silica fume, fly ash, GGBFS (Ground Granulated Blast Furnace Slag), etc. are the conventional waste materials or by-products from the industries that are efficiently used in the present day construction sector. In the same way, there will be generation of various wastes from aluminium refining industries in the form of dross or slag. Since these wastes are having leachable salts like KCl, direct dispose of such wastes is an issue to be addressed. Utilizing them for landfills may create problem to the surroundings as well as to the ground. Still most of part of the dross is being disposed of as landfills, which is causing leaching of toxic metal ions into ground and thereby polluting the ground water (Unger and Beckmann, 1992). Traces of toxic gases like NH_3, CH_4, PH_3, H_2, H_2S, etc. get released when secondary aluminium dross comes in contact with moisture. Recycling of aluminium waste requires only about 5% of the energy required to manufacture aluminium from bauxite ore which makes it important to consider the concept of recycling it. Also, the cost required for collection of new aluminium source, separation can be reduced with effective recycling of the generated waste. Thus, recycling the aluminium waste and producing an engineered product can solve maximum sustainability problems.

Adeosun et al. (2014) used bentonite and aluminium dross in different proportions to study the mechanical and physical behaviour of bricks which had particle size of 106 μm and because of this property, they can be used as refractory materials. Adeosun et al. (2012) added aluminium dross to the polypropylene in different proportions for particle size range between 53 μm and 150 μm and determined the mechanical properties of it. Aluminium dross was added at 15 % by weight which resulted in the improvement of ultimate tensile strength by 68%. When it is added at 50 % and at 8 %, there was increase in density by 54 % and water absorption by more than 100 % respectively. Also, at 15 % addition of aluminium dross it was same impact resistance when compared to that of the conventional polypropylene without any addition. Petavratzi and Wilson (2007) produced roof tiles, bricks from the concrete made with aluminium dross as filler material. Non-aerated concrete is produced by them by using aluminium dross. Ewais et al. (2009) did the experimentations on aluminium slag/dross and aluminium sludge which has main source of CaO and Al_2O_3 and manufactured calcium aluminate cement by adding extra alumina into the matrix.

Ozerkan et al. (2014) determined the behaviour of concrete made using aluminium dross with respect to its strength and corrosion resistance. They suggested that the corrosion resistance of the mortar mix or concrete mix can be improved by using aluminium dross as an ingredient in its composition in certain limited quantity. Kazjonovs and Korjakins (2013) utilized municipal solid waste, container glass and aluminium scrap waste to produce expanded aggregates which are lighter in weight and used for different construction purposes.

Elinwa and Mbadike (2011) used the waste from aluminium industry for producing concrete with various percentage replacement of cement. They found out that the replacement of cement by 10 % to 15 % aluminium waste yielded the flexural strength and compression strength nearer to that of the control mix of concrete. Also, they identified retardation in the concrete setting time by addition of aluminium waste material. This makes the concrete suitable for hot weather construction works (Elinwa and Mbadike, 2011). In India, there is over 120,000 tonnes of aluminium dross is produced from various industries and if all this can be effectively utilized in the concrete production, there can be noticeable decrease in overall cost of concrete construction works. Also, the carbon foot print in the environment can be reduced with reduced energy consumption in the production of cement.

The research works done on concrete produced with secondary aluminium dross as an ingredient in the mix is very less and the utilization of this dross in the construction sector needs more importance. For using the concrete in the road construction sector, suitable concrete mix is designed and its strength properties are determined in this work to know its suitability.

2. Experimental Investigations

For the present investigation, the sample of secondary aluminium dross is obtained from M/s Udyog Alloys (P) Ltd, Mumbai, Maharashtra, India. The wastes are irregular in shape, black in colour and contain small particles of aluminium produced by burning aluminium scraps (raw material) in a furnace at about 1900^{0}C. The collected sample was washed 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 2.64 and bulking of sand is 4.5. Fineness modulus of fine aggregate is 3.78. The maximum nominal size of coarse aggregate is 20 mm. The specific gravity and fineness modulus of coarse aggregate are 2.69 and 3.04 respectively. Since the ordinary potland cement production is not environment friendly, fly ash is added as an admixture and Portland Pozzolana Cement is manufactured commercially. Portland Pozzolana Cement (PPC) with 25 to 31 % of fly ash is a better alternative to the Ordinary Portland Cement (OPC). The chemical composition of aluminium dross after water wash treatment and portland pozzolana cement are given in Table 1. Figure 1 shows the aluminium dross sample.

Table 1. Composition of Portland Pozzolana Cement and aluminium dross

Chemical composition	PPC	Aluminium dross
Al_2O_3 (%)	7-10	63
SiO_2 (%)	28-32	4-6
P_2O_5 (%)	-	0.57
SO_3 (%)	2.4-2.8	1.37
MgO (%)	1-2	0.45
CaO (%)	41-43	4-20
ZnO (%)	0.93	-
AlN	-	0.1
Loss on ignition	3.0-3.5	0.05-5.0

*Source: (Song et al. 2016) and (Girish et al. 2016; Sriraksha et al. 2017)

Figure 1. Aluminium dross sample

The physical properties of Portland Pozzolana Cement (PPC) and Aluminium dross are tabulated in Table 2.

Table 2. Physical properties of Portland Pozzolana Cement and aluminium dross

Property	PPC	Aluminium dross
Specific gravity	2.9	2.9
Particle size range (μm)	30-50	45-150
Normal consistency (%)	32	44
Initial setting time (min)	50	140
Final setting time (min)	570	280

In the current work, 5%, 10%, 15% and 20% of aluminium dross is used with respect to weight of the PPC. Figure 2 shows the normal consistency of paste at different percentage replacement of aluminium dross.

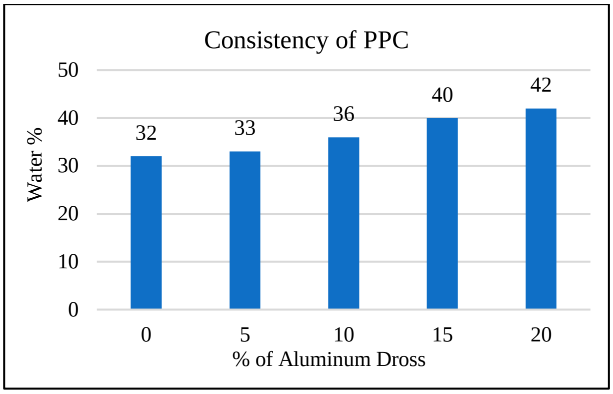

Figure 2. Normal consistency of cement paste with varying percentages of aluminium dross

The normal consistency is 40% for 15% replacement of cement by dross and it is 42% for 20% replacement as per the figure shown above. When the replacement is higher, the water demand in the matrix increases due to the increased surface area of the aluminium dross material. When the weather and temperature are considered while laying the concrete in the field practically, there can be variation in the workability of the mix with respect to the aluminium dross replacement levels. This is due to the effect of aluminium dross in retarding the setting time of the mix. Water gets evaporated from the mix when it is exposed to the hot weather making the concrete to undergo thermal cracks due to insufficient water for hydration. So it is essential to reduce the rate of setting of concrete in the hot whether areas. The concrete produced using aluminium dross as binder has direct influence on the setting time and helps the laying of concrete in the regions with hot weather. Slowdown of hydration of concrete and adsorption of nuclei of calcium hydroxide in the mix makes the concrete to set at a slower rate when aluminium dross is used as partial replacement for cement.

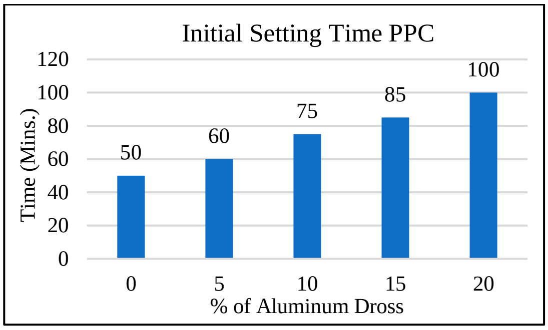

Figure 3. Variation of initial setting time with aluminium dross

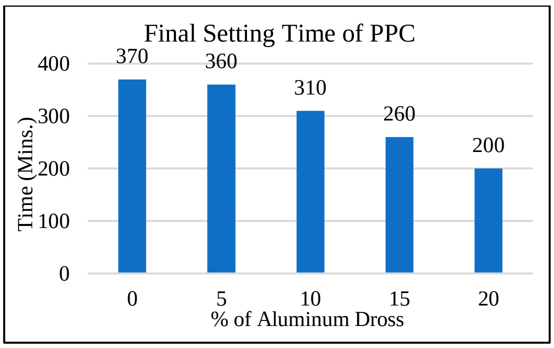

Figure 4. Variation of final setting time with aluminium dross

The variation of initial and final setting times with respect to different percentage of aluminium dross replacement is as shown in the figures 3 and 4. With the increase in percentage of aluminium dross replacement the initial setting time is also getting increased as per figure 3. From figure 4, it can be observed that the final setting time is getting decreased with increase in the percentage of aluminium dross replacement. Aluminium dross has certain quantity of silicates and that quantity is the deciding factor in retarding the initial setting time. Significant amount of water can be absorbed by aluminium dross particles due to the high surface area of nano particles present in aluminium dross. During the hydration of cement, excess of $Ca(OH)_2$ is produced from aluminium dross and it reduces the pozzolanic reaction inside cement matrix. This is the reason for retarding effect of the aluminium dross. Hence, aluminium dross is a good material for retarding the rate of setting and it is suitable for hot weather concreting applications.

Table 3. Properties of fine and coarse aggregates.

Property	Fine aggregates	Coarse aggregates
Specific gravity	2.78	2.69
Fineness modulus	2.64	3.04
Water absorption	0.8 %	0.45 %
Grading zone	II	I
Crushing value	-	24.50 %
Impact value	-	22.30 %
Abrasion value	-	20.25 %
Combined flakiness and elongation index	-	29.12 %

Portland Pozzolana Cement, fine aggregate, coarse aggregate constitute the control mix of concrete which has water to cement ratio of 0.45, named as M1 mix. Table 3 shows the properties of fine and coarse aggregates used in the mix. Aluminium dross contents of 5%, 10%, 15% and 20% by weight of cement are added to the mix and named as M2, M3, M4 and M5 respectively. Slump requirement and quantity of binder is taken as same for all the mix combinations. There was need for adding more water to the mix to achieve required workability. Water to cement ratio is increased to 0.47, 0.50, 0.52 and 0.55 for M2, M3, M4 and M5 respectively. Properties of fine and coarse aggregates taken for the mix design are as tabulated in table 3. For the control mix of concrete designed for M40 target compressive strength, the proportions of the mix were 1:1.74:3.04 (Cement : Fine aggregate : Coarse aggregate). For the workability requirement, extra water is added to the other mix combinations. For compressive strength test, 100 mm × 100 mm × 100 mm sized cubes and for split tensile strength test 150 mm diameter and 300 mm height cylinders were casted. Curing was done for 3, 7 and 28 days and tested at the end of the curing period. 500 mm X 100 mm X 100 mm sized beam specimen were casted to test for flexural strength of concrete beams. After casting, the specimen were demoulded the next day and kept in a water tank at room temperature for the respective curing periods. Higher the replacement percentage of aluminium dross, expansion rate of the specimen was more. Because of the air entrainment the expansion of the matrix occurred and concrete showed swelling effect immediately after casting. The water washed aluminium dross gave very less or negligible expansion at 20 % replacement level. Beyond 20 % replacement, expansion was higher and hence only upto 20 % replacement is considered.

Table 4. Variation of compressive strength for different replacements of aluminium dross

Mix	Compressive strength, MPa		
	3 Days	7 Days	28 Days
M1	19	32	47
M2	18	28	44
M3	17	27	42
M4	15	24	40
M5	12	19	36

The variation in compression strength of concrete with secondary aluminium dross is as shown in Table 4. Higher the percentage of aluminium dross in the concrete lesser is the compression strength as per the results obtained. The compression strength of the concrete gets increased with curing period. 40 % to 50 % of the 28 days strength is achieved in 3 days curing period and 60 % to 70 % is achieved in 7 days curing period. There was less reduction in strength up to 15 % aluminium dross replacement ad it achieved the target strength of M40 as per the design requirement. There was more than 30 % lesser strength obtained for 20 % replacement when compared to the control mix of concrete. The handling of specimen itself was difficult for 20 % replacement because of improper bonding and specimen tends to get broken. Air entrainment can be considered as the main reason for reduction in the strength. If the air entrainment becomes higher the strength reduction becomes even worse. The variation of compression strength for different curing periods is as shown in figure 5.

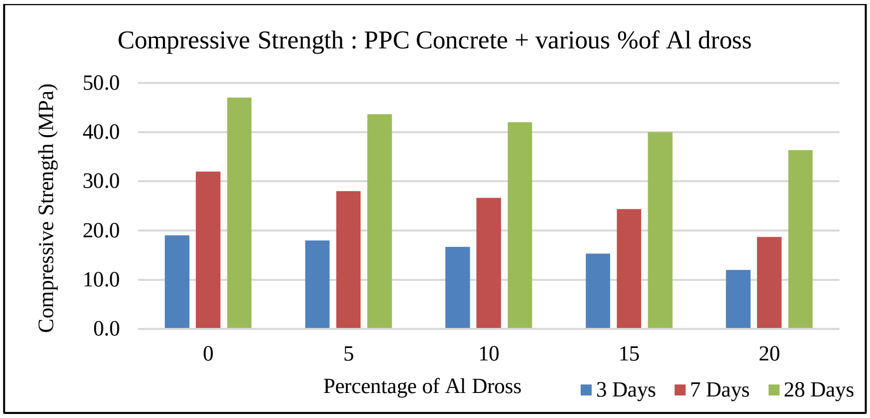

Figure 5. Variation of compressive strength for different replacements of aluminium dross

Table 5. Variation of split tensile strength for different replacements of aluminium dross

Mix	Split tensile strength, MPa		
	3 Days	7 Days	28 Days
M1	2.1	3.2	3.8
M2	1.8	2.8	3.3
M3	1.3	2.2	2.8
M4	1.2	1.9	2.5
M5	1.1	1.4	2.0

The variation of split tensile strength with varying aluminium dross replacement is as shown in table 5. Similar trend is observed in case of split tensile strength as seen in compression strength results. Strength is getting increased with increase in the curing period. For higher aluminium dross replacement, the strength reduction is significant. Up to 15 % replacement it is found to be comparable with the conventional concrete mix. Beyond 20 % replacement is not preferable with respect to split tensile strength test results.

Variation of flexural strength with respect to varying percentage replacement of aluminium dross is as presented in table 6. As seen in compression and split tensile strength results, the flexural strength is also satisfactory only up to 15 % replacement of aluminium dross. M5 mix with 20 % replacement is giving more than 20 % lesser strength compared to the conventional concrete mix which is not preferable. So only up to 15 % replacement of aluminium dross can be considered.

Table 6. Variation of flexural strength for different replacements of aluminium dross

Mix	Flexural strength, MPa
M1	5.1
M2	5.0
M3	4.9
M4	4.6
M5	4.1

After 28 days of curing, the specimens were taken out of the curing tank and the water absorption test is conducted as per the procedure of ASTM C642 on the standard cube sample of 100 mm X 100 mm X 100 mm. Table 7 shows the average water absorption values for different percentage of aluminium dross replacement.

Table 7. Water absorption values for different aluminium dross replacement

Aluminium dross replacement, %	Water absorption, %
0	1.3
5	2.3
10	3.3
15	4.3
20	6.2

Control mix of concrete gave 1.3 % water absorption value as per the results obtained. With the increase of aluminium dross replacement, the water absorption also increases. This is due to the increase in void spaces of mixes with aluminium dross. For 15 % replacement, the water absorption value obtained is more than 50 % of that of the control mix of concrete.

There is no much decrement in strength up to 15 % aluminium dross replacement in comparison with control mix of concrete. Experimental results prove that the percentage replacement cannot be more than 15 % since it can achieve the target strength requirement as per the design. Other cementitious materials can be blended with the aluminium dross and performance is measured to obtain better results. Based on the requirement and intended purpose and also the availability of materials, the appropriate mix can be chosen.

3. Conclusions

Hot weather increases the rate of hydration of concrete making it to set before proper laying and compacting. The initial setting time of the concrete with aluminium dross is retarded and final setting time is accelerated, which makes it suitable for hot weather conditions. Air entrainment into the concrete makes it to expand with increasing percentage of aluminium dross replacement. This expanding property makes it useful in producing subfloors of buildings, precast pavement slabs, precast panels and blocks. Workability of the mix reduces when aluminium dross is added and demands for more water. Since aluminium dross has high specific area, absorption of water over it reduces the water available in the system for hydration. This decreases the consistency as well. Mechanical properties like compression, tension and flexure are getting decreased with higher aluminium dross replacement. For M40 grade concrete designed in this work, 15 % of aluminium dross replacement is found to be optimum. Overall, the aluminium dross replaced concrete is sustainable because of reduction in the carbon foot print by reducing the energy consumption during cement manufacturing, reduction in environmental pollution and reduction in total cost of the work by replacing cement. 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.

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