FLY ASH AGGREGATES FOR PRODUCTION OF LIGHTWEIGHT CONCRETES

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ABSTRACT

Fly ash aggregates produce lightweight concretes (LWCs) with adequate mechanical strengths. It is necessary to confirm whether LWCs also offer protection to the steel reinforcement. Test data indicate that LWCs with 'sintered fly ash aggregates' provide adequate protection to steel, especially when fly ash is added as 'partial cement replacement' in concretes. Fly ash is converted into coarse aggregates by 'pelletising' followed by 'sintering' actions. Powdery granules of FA can be agglomerated minerologically by sintering and then used as CA. These sintered fly ash aggregates (SFAAs) are highly porous and hence, concretes made from them aggregates would be also lightweight in nature. These lightweight concretes (LWCs) would absorb comparatively more water than the conventional 'normal weight concretes' (NWCs). It is necessary to examine whether LWACs have reduced resistance to steel embedded in concrete. This aspect is discussed in this paper and the test data shows that by appropriate design of binder matrix, it is possible to achieve satisfactorily corrosion resistance behaviour in concretes containing SFAAs as coarse aggregates.

Keyword: *Mechanical, agglomerated, replacement, conventional, resistance*

1. DETAILS OF EXPERIMENTAL WORK

A LWC with SFAAs (satisfying the requirements of ASTM C 330) as CA and having weight proportions of binder: sand: CA at 1:1:2 was evolved with adequate workability [LWC0]. The cement content of LWC) was replaced by 25% and 50% FA to obtain two more LWC mixes, LWCF25 and LWCF50, respectively. Water-binder ratios of the mixes were adjusted to achieve similar levels of workability. Besides, compressive strengths (on cube specimens of 100 mm size) at ages of 3, 7, and 28 days, corrosion resistances of these mixes were investigated by Rapid Chloride Permeability Test (RCPT) of ASTM C 1202 on cylindrical specimens (50mm thick, 100 mm dia) and measuring the electrochemical parameters on slab specimens [300x300x50mm with a central 20mm MS rod]. As stated earlier, the common factor for the three mixes studied is the relative proportions of Binder: Sand: Coarse aggregate and almost similar workability. When fly ash is added as part of the binder, the strengths of mixes containing FA can differ. However, for technical suitability of any mix for given particular application, the properties of the mixes would serve as basis for selection of any one of the mixes studied. Properties materials and test results are given Tables 1 to 3; the test results are analysed with reference to criterion given in Tables 4 to 6.

Table 1 Properties of materials used in the study

S No	Property	Cement	Fly ash	Sand	Coarse Aggregate
1	Type	43 Grade OPC	Class F	River	Crushed granite
2	Conforming Code	IS:8119	IS:3812	IS:383	IS:383

3	Specific gravity	3.15	2.2	2.81	2.89
4	Fineness (Blaine) m^2/kg	285	310	-	-
5	Standard consistency	30%	-	-	-
6	Compressive Strength	45 MPa (IS:4031)	-	-	-
7	Cementing efficiency, 'k'	-	0.8 @ 28 day	-	-
8	Bulk density, kg/m^3	1610	995	1628	1720
9	Fineness modulus	-	-	2.81	6.5
10	Nominal MSA, mm	-	-	-	20

Table 2 Properties of Sintered Fly Ash Aggregates (SFAAs)

S No	Property		Value
1	Sizes produced mm		1 to 20
2	Shape (Approximately)		Spherical
3	Angularity number' (AN) (For spheres, Voids content=26%, AN =0)		5 for 10 mm
4	Specific gravity of grains of SFAAs		1.707
5	Saturated water absorption		21.5
6	Oven dry condition	Apparent specific gravity	1.287
7	Air dry condition	Apparent specific gravity	1.289
8	Saturated Surface Dry	Apparent specific gravity Loose bulk density, kg/m^3	1.564 820.1

Table 3 Chloride penetration resistances of concretes (ASTM C 1202)

Electric charge passed (Coulombs)	Penetration resistance	Type of LWCs (after 100 days of exposure to NaCl solution)
>4000	High	
2000-4000	Moderate	LWC0
1000-2000	Low	LECF25
100-1000	Very low	LECF50
<100	Negligible	

A laboratory ribbon type horizontal mixer was used. The mixes were cohesive and could be easily compacted in steel moulds using a table vibrator. Steel moulds were used to cast cube and cylindrical specimens, and wooden mould for slab specimens. The test specimens could be demoulded easily after 24 hours of casting and they were submerged in water for effecting curing process.

Table 4 Details of SFAA concrete mixes and test results

Mix ID			LWCO	LWCF 25	LWCF 50
Type of fine aggregate			River sand		
Water-binder ratio			0.30	0.32	0.42
Binder:Sand:Coarse aggr. (weight)			1:1:2	1:1:2	1:1:2
Superplasticiser (CAE based)		%	0.02	0.1	0.05
Workability, slump		mm	100	150	125
Compressive strength 3 day		MPa	22	17	13
7 day		MPa	36	30	17
28 day		MPa	44	42	31
f_{c3d} / f_{c28d}		%	50	40	42
F_{c7d} / f_{c28d}		%	82	71	55
RCPT [ASTM C1202]		Coulombs	2410	1990	995
ECPs from Gcor Initial (After 28 days of water curing)	ECCR	μA/cm^2	0.06	0.05	0.03
	ECV	mV	-381	-367	-451
	ER	kilo-ohm-cm	6.2	12.1	13.3
After exposure of 100 days to 3.5% NaCl solution	*ECCR*	*μA/cm^2*	*3.1*	*0.16*	*0.07*
	ECV	*mV*	*-585*	*-376*	*-368*
	ER	*kilo-ohm-cm*	*3.9*	*11.7*	*13.1*

ECP= Electrochemical parameters, ECCR=Electrochemical corrosion rate, ECVP= Electrochemical voltage potential, ER=Electrical resistivity

Table 5a Electrical resistivity of concrete and corrosion rate

[Tay Woodrow Research Lab, UK, 1980]

Concrete resistivity	Corrosion rate	Type of LWCs (after 100 days of exposure to NaCl solution)
<5 kilo-ohm-cm	Very high	LWC0
5-10 kilo-ohm-cm	High	
10-20 kilo-ohm-cm	Low	LWCF25 and LWCF50
>20 kilo-ohm-cm	Negligible	

Table 5b Electro-chemical potential of concrete and corrosion rate (ASTM C 876)

Less negative than -200 mV (Cu/$CuSO_4$)	90% probability of no corrosion
-200 mV to -350 mV	Increasing probability of corrosion
More negative than 350 mV	90% probability of corrosion

Table 6 Corrosion rate of steel in concrete (Andrade & Alonso, 2001]

Corrosion rate of steel in concrete	Corrosion rate	Type of LWCs
<0.1 μA/cm^2	Negligible	LWCF50
0.1 to 0.5 μA/cm^2	Low	LWCF25
0.5 to 1 μA/cm^2	Moderate	
>1 μA/cm^2	High	LWC0

2. DISCUSSION OF TEST RESULTS

2.1 Compressive strengths:

The 28 day compressive strengths of LWC mixes exceeded 30 MPa [Table 3]. These concretes can be taken to be equivalent to M25 grade. As per IS:456-2000, a minimum structural grade is M20 and hence, the LWC mixes of the present study have potential for use as structural material in concrete constructions. Addition of FA as partial 'cement replacement material' (CRM) resulted in more gradual gain of strength, due to the slower hydration reactions in cement-fly ash paste than in cement paste alone [Rajamane, 2003e; Joshi, 1999]. It is well known fact that after 28days, fly ash based mixes would gain more strength. However, since most of the structural designs still tend to consider 28 day strength, this age was taken as basis for the calculating the rate of strength gain..

2.2 Chloride Permeability of Concrete Mixes

This is tested by using provisions of ASTM C 1202 and the quantity of electric charge (EC) (measured in coulombs) conducted through the disc specimens is taken as a measure of resistance of concretes to penetration of chloride ions. In the present study, LWCs with 0, 25%, and 50% FA had 'moderate', 'low, and 'very low' degrees of chloride penetration resistances [Table 4]. The reduction in chloride permeability of LWCs with FA may be attributed to the pore refinement because of pozzolanic reactions and fine filler action of fly ash which has been a well documented aspect of binder matrix containing FA [Rajamane, 2003f; Malhotra, 1994].

2.3 Electrochemical Parameter Measurements

The 'electrochemical parameters' (ECPs) of the 28 days cured slab specimens were determined using an equipment known as GECOR which utilises electrochemical polarisation resistance technique. The measurements were made after exposure to 3.5% NaCl solution.

Initial test data on ECPs, before the start of exposure to corrosive environment indicate the negligible levels of corrosion activity on the steel bar surface. After 100 days of exposure, the LWCs were found to be superior to CC. The LWC with 50% FA had better resistance to corrosion than that with 25% FA. Using the classification of corrosion rate corresponding to concrete resistivity, given by Tay Woodrow Research Laboratory of UK (1980) [Table 5a], it is seen that the corrosion rate status changes was from 'high' to 'very high' for LWC without FA and in LWCs with FA, the corrosion rate remained at 'very low'. Similar observation can be made based on the corrosion rate classification by Andrade and Alonso [2001] in Table 6. This can be attributed to the lower chloride permeability of FA based cement matrix as observed in RCPT. The actual corrosion rates measured by GECOR in LWCs indicate the beneficial effects of FA in LWCs due to reduction in pH of pore solution because of reaction of FA with calcium hydroxide of the hydrated cement [Rajamane, 2003g and 2003h]. It is to be noted here the half cell potential values at 28 days LWCs are observed to be more negative than -350 mV, indicating a higher corrosion activity around the steel present inside the concrete matrix [Table 5b]. This could be due to either inadequacy of 28 days of curing period to develop denser matrix system, or the porous nature of LWC itself. However, potential measurements are generally taken as only indicative in nature and they can not be taken as definite pointers to the actual status of corrosion always and this has been commonly seen noticed many authors [Ping et al, 1997]. In the present study, the relative values of half potential before and after accelerated corrosion test period are considered for understanding comparative durability of LWCs with and without FA.

The above discussion indicates that LWCs containing SFAAs resist corrosion of steel provided the cement in the binder portion is partially replaced by FA. The internal energy content of Portland cement is very high [Neville, 1996] and partial substitution of the cement by FA reduces the total internal energy content of concrete thereby making the concrete more 'green' [Rajamane, 2003f].

3. CONCLUDING REMARKS

1. Sintered fly ash aggregates (SFAAs) can be used as coarse aggregates (CAs) to achieve 28-day compressive strengths of 30 to 45 MPa in concretes which are 'lightweight concretes' (LWCs).
2. LWC without fly as (FA) has 'moderate' chloride permeability as per ASTM C1202. However, with 25% FA in LWC, this permeability becomes 'low', which further reduces to, 'very low' at 50% FA. Thus, addition of FA to LWC is highly beneficial.
3. Accelerated corrosive exposure to sodium chloride solution indicates that LWC without FA offers adequate protection to steel embedded in concrete, as by observed by satisfactory values of electrochemical parameters (ECPs) such as 'electrochemical corrosion rate' (ECCR), 'electrochemical voltage potential' (ECVP) and 'electrical resistivity' (ER).
4. The study showed that the 'light weight concretes' can be produced by using 'sintered fly ash aggregates' as coarse aggregates. Durability of these concretes is enhanced significantly by use of fly ash as 'cement replacement material', particularly adopting the 50% FA content in binder of concrete.
5. Cement content of lightweight concrete (LWC) is generally more than the normal weight concrete (NWC) when measured by weight and this is very commonly observed in the test data available in published literature. This is due to lower density of lightweight aggregates (LWAs).However, if the contents of LWC and NWC are considered on absolute volume basis, the difference in cement contents would not look quite contrasting. Moreover, due to porous nature of LWAs, the water is held in LWCs over longer period which reduces the drying shrinkage cracking possibility. Thus the seemingly higher content of binder paste should not pose problems in LWCs. One can note also that by using FA as 'cement replacement material' (CRM) , the actual Portland content of concrete decreases which would reduce the heat of hydrated generated in the unit mass of concretes.

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5. REFERENCES

1. Ambily P S and Rajamane N P, [2007a], "Self curing concrete – an introduction", Proceed. of CSIR sponsored National Seminar Recent Trends in Concrete Technology (NSRTCT-2007), Kongu Engineering College, 8-9 March, Erode, pp 88-89
2. Ambily P S and Rajamane N P, [2007b], "Self curing concrete – an introduction Part 1", Masterbuilder, Vol. 9, No. 6, June, pp 116-123.
3. Ambily P S and Rajamane N P, [2007c], "Self curing concrete – an introduction Part 2", Masterbuilder, Vol. 9, No. 7, July, pp 108-114
4. Ambily P S and Rajamane N P, [2007], "Self curing concrete – an introduction", New Building Materials and Construction World, Vol. 13, No. 1, July, pp 74-86
5. Bentz, D.P., [2002a], "Influence of Curing Conditions on Water Loss and Hydration in Cement Pastes with and without Fly Ash Substitution," NISTIR **6886**, U.S. Dept. Commerce.

6. Bentz, D.P., and Snyder, K.A., [1999a], "Protected Paste Volume in Concrete: Extension to Internal Curing Using Saturated Lightweight Fine Aggregates," Cement and Concrete Research, **29**, 1863-1867.
7. Bentz, D.P., and Stutzman, P.E., [2006a], "Curing, Hydration, and Microstructure of Cement Paste," ACI Materials Journal, **103** (5), 348-356.
8. Bentz, D.P., Garboczi, E.J., and Snyder, K.A., [1999b], "A Hard Core/Soft Shell Microstructural Model for Studying Percolation and Transport in Three-Dimensional Composite Media," NISTIR **6265**, U.S. Department of Commerce.
9. Bentz, D.P., Halleck, P.M., Grader, A.S., and Roberts, J.W., [2006b], "Direct Observation of Water Movement during Internal Curing Using X-ray Microtomography," Concrete International, **28** (10), 39-45.
10. Bentz, D.P., Lura, P., and Roberts, J.W., [2005a], "Mixture Proportioning for Internal Curing," Concrete International, **27** (2), 35-40.
11. Bilek, B etal, [2002], "The possibility of self-curing concrete Proc Name Innovations and developments in concrete materials and construction". Proc. Intl Conf. University of Dundee, UK. 9-11 September.
12. Bungey JH, Millard SG and Grantham MG, [2006], Testing of concrete in structures. 4th edition. Taylor and Francis, London and New York