SPECIAL GRADE FLY ASH to AS 3582.1-1998

An Alternative to silica fume in High-Performance Concrete

ASH DEVELOPMENT ASSOCIATION

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FLY ASH REFERENCE DATA SHEET

No. 4. 1999

Silica fume (SF) is recognised as a highly-reactive pozzolan and has been considered by many to be an essential component of high-performance concrete. High-performance fly ash, complying with **Special Grade** (AS 3582.1-1998, Fly Ash) has been proposed and evaluated as a realistic alternative. Several sources of Special grade fly ash (sgfa) are now available. The properties of concrete produced from these ashes has been shown to be at least equivalent to concrete containing silica fume and potentially superior in the long term.

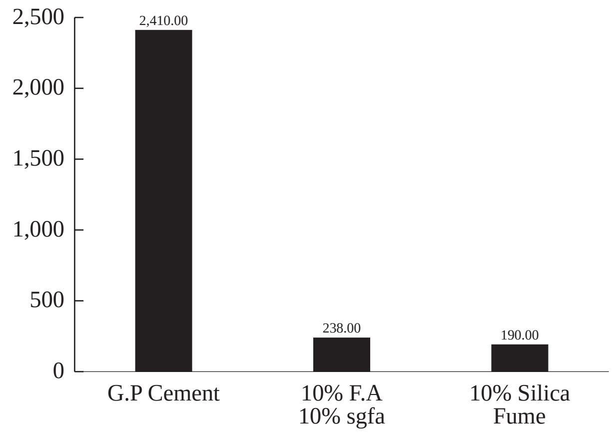
The distinctive property of good quality fly ash is its ability to reduce the water requirement of concrete. This effect varies with the strength level, the amount and quality of the fly ash used and the characteristics of the particular cement. The effect depends in part upon the fly ash filling voids that would otherwise be filled with water. Very fine ash is often the most effective, both for water reduction and for other desirable properties, challenging silica fume in comparisons at equal workability.

Most of the desirable attributes of fly ash concrete depend on combinations of paste enhancement, water reduction, and pozzolanic activity, resulting in enhancement of the pore distribution in the paste fraction of the concrete. However, in the specific cases of marine exposure and alkali-silica reaction (ASR), fly-ash concrete performs better than would be predicted from paste enhancement alone.

When fly ash is used as a partial cement replacement in mass concrete, both the rate of temperature rise and the maximum temperature reached are significantly reduced. Concrete containing fly ash typically sets more slowly and gains strength more slowly at early ages than concrete without fly ash. This is based on fly ash concrete in which the cement content has been reduced and, effectively, the ratio of water to portland cement has increased. At ages beyond 7 days, the rate of strength gain is greater than for reference concrete, when mixtures are proportioned for equal strength at 28 days. Strength at early ages can be enhanced by the use of WRA or HRWR.

Special Grade fly ash is becoming available as a commercial material in several countries, including the United States and Australia. Shelton (Table 1) reported on trials of sgfa from Texas at fixed cement content of 330 kg/m^3 with HRWR (superplasticiser) nearly 1 litre/100 kg of binder. Strengths with 33 kg of added sgfa (10% of cement) exceeded those for equal SF addition at all test ages. Higher additions of sgfa further reduced water requirement and increased strength. Rapid chloride permeability results were comparable. Butler (Table 2) reported tests on concrete mixtures containing ternary blends of SF and fly ash and compared these with a reference concrete containing **sgfa** and fly ash. Variables in the comparison were the source of fine pozzolan and the water requirement for equal slump. Australian, Norwegian, and American sources of SF were used in the comparison.

Chloride Permeability (ASTM C1202)



AAR Expansion Series B

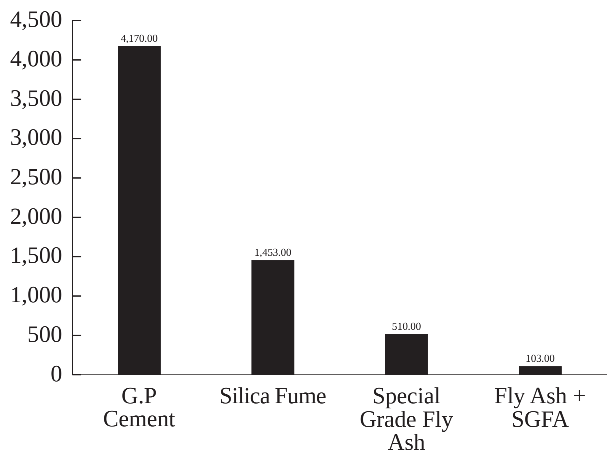


TABLE 1

Performance of Special Grade Fly Ash in concrete compared to concrete containing Silica Fume (as additions to 330kg/m³ normal portland cement)

Addition	10% Silica Fume	10% sgfa	12.5% sgfa	15% sgfa
Water	165	165	143	121
w/(c+m)	0.4	0.4	0.33	0.26
Slump	125	210	210	210
Compressive Strength, MPa				
1 day	24.0	26.5	30.5	35.0
3 days	32.5	36	42	48.5
7 days	40.5	44.0	50.5	56.0
28 days	49.0	55.5	63.5	73.5
56 days	50.0	58.5	64.5	73.5
ASTM C1202 Permeability, Coulomb				
@ 56 days	136	151		

TABLE 2

Performance in concrete of Ternary Blends containing Fly Ash plus Special Grade Fly Ash (S.Aust.) or Silica Fume

Cement, kg	350	350	350	350
Fine Grade Fly Ash, kg	50	50	50	50
Special Grade Fly Ash, kg	Nil	Nil	Nil	35
Silica Fume, kg	35 (Aust)	35 (Nor)	35 (USA)	Nil
High range WRA, L	6	6	6	6
Water, kg	186	187	168	144
Slump, mm	175	180	180	205
Compressive Strength, MPa				
3 days	34	32	34	49
7 days	48	44	46	58
28 days	69	63	65	68
1 day, accelerated	52	44	45	57
Water Absorbtion, %	1.0	1.2	1.1	0.8
Rapid Chloride Permeability (ASTM C 1202), Coulomb				
54 +/- 2 days	390	750	500	860

DISCUSSION In both of the above test series, advantage has been taken of the improved workability in concrete containing sgfa when the HRWR admixture dose rate is held constant. This approach is deemed to be valid. In the following work with Queensland materials, additional HRWR was used in concrete mixes containing SF to compensate for the potentially-higher water demand. In comparing the relative performance of **sgfa** against SF in Tables 3 & 5, allowance should be made for this compensation in favour of silica fume.

Strength Series B

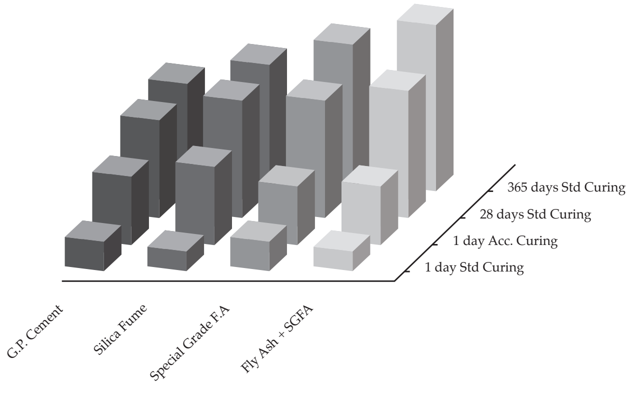


TABLE 3

Comparisons with Queensland materials, all batches contain 4L of WR admixture plus HRWR as listed

Trial Mix	A4	A5	A6	B1	B2	B3	B4
GP Cement	450	400	450	500	450	450	400
Tarong Fly Ash		50					50
Special Grade FA	50	50				50	50
Silica Fume			50		50		
HRWR, L per cu.m	5	5	10	5	8	5	5
Water, L per cu.m	145	140	125	155	165	140	135
Slump, mm	155	155	160	230	180	190	100
Compressive Strength							
1 day A/c	57.0	53.5	59.0	58.5	67.0	53.5	57.0
1 day std. Curing	35.5	33.5	25.0	38.5	34.0	39.5	35.5
28 days std. Curing	97.9	95.5	90.5	76.0	87.0	87.5	90.5
365 days std. Curing				81.0	91.5	98.0	108.0
Shrinkage 56 days	575	612	596	493	486	413	400
Ditto after steam cure				436	254	330	308
ASTM C1202 Coulomb	680	410	455	2640	310	325	190
AAR expand ustrain							
11 or 12 months	230	210	1270	4170	1453	510	103

TABLE 4

Typical physical and chemical analysis of the sgfa used in the Qld trials

Physical			**Chemical**	
Colour:		Light brown	S_1O_2	46.7%
Particle Shape:		Spherical	Al_2O_3	31.2%
Relative Density:		2.55	Fe_2O_3	11.0%
Bulk Density:		900kg/m^3	CaO	3.8%
Moisture Content:		0 - 0.3%	MgO	2.4%
LOI:		0.4%	Na_2O	0.25
Fineness	<15 um:	99%	K_2O	0.2%
	<5 um:	91%	SO_3	0.2%
	<1 um:	46%		
Mean Particle Size: <1.2 um				

TABLE 5

Further Qld. concrete trials at 500 kg per cubic metre of total binder

Results / Mix	**G.P. Cement**	**10% Fly Ash 10% sfga**	**10% Silica Fume**
HRWW, L per cubic metre	4.4	5.6	7.3
Water, L per cubic metre	153	138	158
Slump, mm	150	146	150
Compressive Strength			
1 day	36.5	32.0	32.5
3 days	58.5	57.0	56.5
7 days	66.0	70.0	75.5
28 days	78.0	91.5	87.5
56 days	82.5	98.5	92.5
Other Properties			
Drying Shrinkage @ 56 days	490	455	425
ASTM C1202 @ 3.5 months	2410	238	190

CONCLUSIONS

When appropriately interpreted, the above results indicate that **special grade fly ash** is a valid and relatively economical alternative to silica fume in high-performance concrete.

- Compressive strengths can be achieved or exceeded at all ages from 1 day.
- Low drying shrinkage is readily attained, especially with steam curing.
- Long-term expansions due to alkali-silica reaction are contained far better than with other binder combinations.
- Performance in the ASTM C1202 procedure (Electrical Indication of Concrete's Ability to Resist Chloride Ion Penetration) is comparable to that achieved with silica fume.

REFERENCES

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3. Butler, W.B., Superfine Fly Ash in High Strength Concrete", Concrete 2000. American Concrete Institute, (ACI) SP121, Editor Hester, pp331-349, 1990 Conference Proceedings, Editor R. Dhir, Dundee, Scotland, September1994.

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