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ABSTRACT

China has one of the largest coal mining industries in the world. Electricity in this country is mostly generated by coal-fired electric power plants. These plants produce huge amounts of ash each year. In 1988, Shanghai city alone produced nearly 1.8 million tons of ash. During the last two decades, a substantial amount of research work conducted by the Shanghai Research Institute of Building Sciesces (SRIBS), in coordination with other research centers in China, has resulted in large -scale utilization of fly ash as construction materials. The technologies established for fly ash utilization in concrete blocks, decorative tiles, pumped concrete, and lightweight aggregates concrete are discussed in this paper.

INTRODUCTION

Fly ash and bottom ash is a solid by-product material produced in a coal-burning power plant. As a developing country, China's economic growth is expected to continue rapidly in the decades ahead. Since China, like the United States, possesses abundant coal reserves, coal-burning electricity gene-ration is the current principal energy source. The total amounts of fly ash and bottom ash (slag) produced from coal-fired power plants increases yearly along with the development and huge demand for electricity. The production statistics from 1979-1988 is listed below in Table I [l].

Table 1: Statistics for Fly Ash and Slag Production in China from 1979 to 1988
(unit: Millions of tons)

Year / Term	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988
Total Production	26.8	25.9	26.6	27.5	30.2	33.9	37.7	42.3	48.1	55.5
Fly Ash Production	22.0	21.2	21.8	22.8	24.4	29.0	32.3	36.1	41.5	48.8
Slag Production	4.7	4.8	4.8	4.7	5.8	4.9	5.4	6.0	6.6	6.7
Total Utilization	2.8	3.7	5.0	4.6	72	6.9	7.8	9.6	11.3	14.2
Utilization Percentage (%)	11	14	19	17	24	20	21	23	24	26

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The bar graph (Fig. 1) compares the production and utilization of fly ash and slag in China from 1979 to 1988 [1].

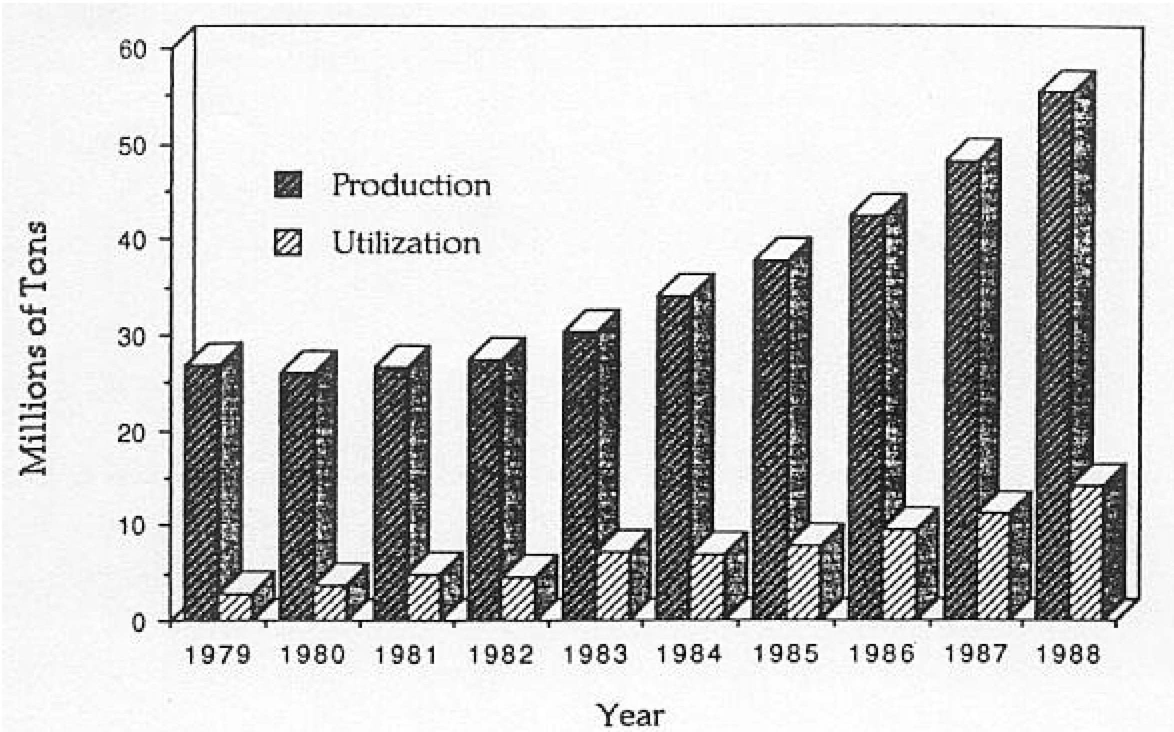

Fig. 1. Total Production and Utilization of Fly Ash and Slag in China 1979-1988

Fly ash utilization in China, up to now, mainly falls into civil engineering materials for construction of buildings and roads, namely as cement admixture, concrete admixture, walling material, road material, and construction backfill. In 1988, total utilization amount exceeded 14 million tons, of which: (1) 5.9 million tons ash and slag were used as admixture in walling material and cement, such as aerated concrete, light-weight aggregate, bricks, blocks, etc-; (2) 0.7 million tons ash and slag were directly used in concrete construction worth such as high-volume fly ash concrete, pumped ready-mixed concrete, dam or mass concrete; (3) 2.2 million tons ash and slag were used in road construction, (4) 4 .3 million tons ash and slag were used as construction backfill; (5) 0.6 million tons ash and slag were used in, agriculture, such as producing fertilizer, to improve the properties of soil; and, (6) miscellaneous use of fly ash and slag were 0.6 million tons, including useful material recycling etc. Fie, 2 shows the percentage of various usage of fly ash in China in 1988 [1].

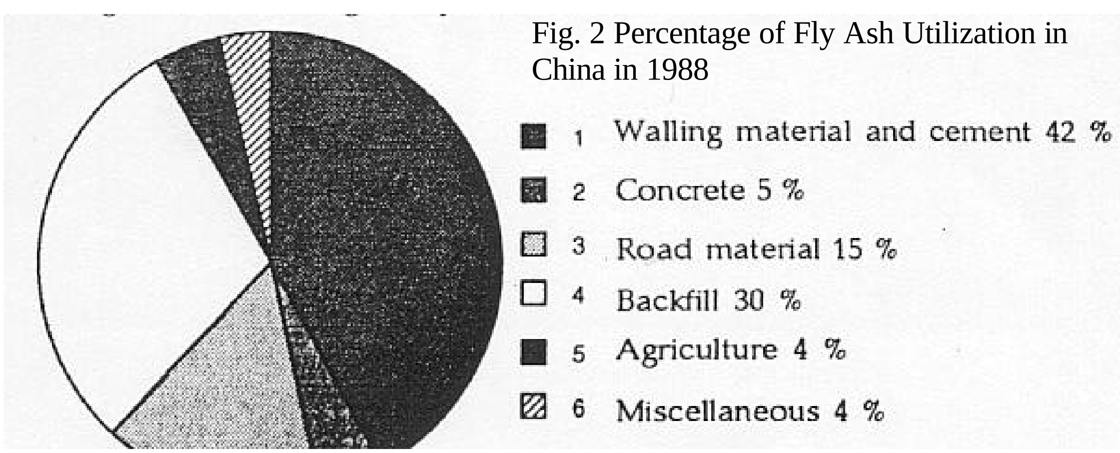

Fig. 2 Percentage of Fly Ash Utilization in China in 1988

In recent years, a substantial amount of research work conducted by the Shanghai Research Institute of Building Sciences (SRIBS), in coordination with other research centers in China, has resulted in large-scale utilization of ash as construction materials.

SEVERAL MAIN RESEARCH ACHIEVEMENTS IN FLY ASH UTILIZATION
Fly ash used as admixture for walling material

(i) Non-cement fly ash concrete blocks [2] Non-cement, steam-cured, fly ash concrete blocks have been popularized since 60's in Shanghai. The standard dimension of these blocks is 880-380-240 mm (34.6-1.5-9.4 in). Its raw material includes fly ash, ground lime, phosphogypsum, and bottom ash (slag) used as aggregates. The Fly ash concrete block can be used as a load bearing wall material for low-cost multi-story residential buildings in non-seismic regions. About 0.25 million M^3 of this block is produced yearly in Shanghai which can be used to construct one million m^2 of residential buildings. According to China's specifications, properties of the fly ash concrete block are listed in Table 2 .

Table 2: Properties of Block

Test	Values	Remarks
Density (kg/m^3) (lb/cu.yd.)	1600~1700 2700~2860	In dry state one day after steam curing
Compressive Strength (MPa), R* (Psi)	10~20 1450~2900	
Prismatic Strength	0.8~0.95R*	
Buckling Strength	0.167~0.25 R*	
Splitting Tensile Strength	0.063~0.1 R*	
Shear Strength	0.12~0.17 R*	
Modulus of Elasticity (MPa) (Psi)	$0.8\cdot10^4$~ $1.2\cdot10^4$ $1.2\cdot10^6$~$1.7\cdot10^6$	Measured when stress is a 0.4~0.6 primati Strength
Strength loss after freeze-thaw cycle (T=15°C, after 15 cycles)	<20%	

R* means compressive strength

The thermal insulation properties of fly ash block wall are superior to that of ordinary clay brick wall. Fly ash concrete shrinkage value is similar to that of cement lightweight aggregate concrete. In the view of the investigations made on about 50 buildings in different regions, it has been found that after a period of 10 years, carbonation depth for the exterior walls was 40 to 60 mm (1.6 to 2.4 in) and that for interior walls was 50 to 100 mm (2 to 4 in). Investigations also showed that the buildings were still in good condition, with carbonated surfaces of fly ash block remaining intact and exhibiting no significant damage. Compared with brick masonry systems, use of fly ash concrete blocks can reduce 12% dead load, increase construction production by 33%, and shorten the work cycle by I/ 3.

(ii) Fly ash and slag decorative tiles [3] Industrial by-products such as fly ash and slag produced by coal-burning power plants could be used as main raw material to produce a new kind of decorative tile (7.9-2.4-0.4 in) for external walls. Tiles are formed by dry mixing and semi-dry forming through pressing and high- temperature sintering. The rate of temperature rise is 200^{o}C/hr up to $1130\text{-}1160^{o}$C. The tiles are fired 16-20 hours in a kiln. The composition of fly ash decorative tile is listed in Table 3. Table 4 shows chemical composition of the tile, and Table 5 shows physical properties.

TABLE 3
Composition of Fly Ash and Slag Decorative Tile

Fly ash and Slag (%)	Clay (%)	Sludge (%)	Mineralizer (%)
45~60	30~35	10~20	10~20

TABLE 4
Chemical Composition of Tile

SiO^2 (%)	Al^2O^3 (%)	Fe^2O^3 (%)	CaO (%)	MgO (%)	K^2O (%)
50.3	25.5	12.2	7.0	3.3	1.42

TABLE 5
Physical Properties of Tile

Water absorption (%)	Shrinkage (%)	Flexural strength (MPa)
5~7	2~4	2.5~3.0 (360~440 Psi)

The fly ash and slag served as an excellent resource as the raw material for manufacturing of these tiles. This kind of decorative tile is light in weight, high in strength, natural in color, good in insulation and has good economic benefits.

Use of fly ash as mineral admixture for concrete

(i) Pumped concrete and mass concrete [4] Research was conducted on pumpability and mass concrete. It required a concrete of 30 MPa (4500 Psi) with slump of 18 ± 3 cm (7 ± 1 in). Research was aimed at technical methods to control slump/workability of pumpable concrete, while keeping the hydration heat released from concrete as little and as slow as possible.

Fly ash was added to the concrete for the purpose of improving workability of the concrete. The ash increased the water content per unit volume of concrete, without increasing the cement content. The use of fly ash as a partial substitute for cement reduced subsequent shrinkage of the concrete and reduced hydration heat, thereby minimizing shrinkage cracks in the mass concrete. In order to prepare the best pumpable mass concrete, the following additional steps were taken: (1) addition of water-reducing admixtures; and, (2) addition of finer fly ash.

Table 6: Physical and Mechanical Properties of Mass Concrete

Cement (kg/m^3) (lb/cu.yd.)		309.0 521	328.5 553	351.0 591	313.7 529	345.0 581	309.0 521
Fly Ash (%)		0	15	0	15	0	15
Cement Replacement (%)		0	10	0	10	0	10
Type of Water-reducer		M	M	NF	NF	SP	SP
Slump (cm) (in)		19.8 7.8	19.2 7.6	20.1 7.9	20.8 8.2	18.2 7.2	18.0 7.1
Compressive Strength R28 (MPa) (psi)		31.4 4553	32.3 4684	34.0 4930	35.0 5075	38.7 5612	34.4 4988
Splitting Tensile Strength (MPa) (psi)		2.6 377	3.3 479	3.2 464	2.9 421	3.0 435	2.9 421
Flexural Strength (MPa) (psi)		5.1 740	5.6 812	5.3 769	4.7 682	5.9 856	6.1 885
Prismatic Strength (MPa) (psi)		24.1 3495	28.3 4104	26.0 3770	24.7 3582	32.9 4771	34.2 4959
Bond Strength (MPa) (psi)		4.3 624	4.5 653	4.5 653	4.0 580	4.7 682	4.3 624
Modulus of Elasticity $*10^4$ (MPa) $*10^6$ (psi)		3.3 4.8	2.7 3.9	4.3 6.2	3.3 4.8	3.5 5.1	3.5 5.1
Permeability Resistance (mark B)		>12	>12	>12	>12	>12	>12
Shrinkage	28-days mm/M in/ft $*10^{-3}$	0.324 3.9	0.303 3.6	0.313 3.8	0.290 3.5	0.333 4.0	0.423 5.1
	90-days mm/M in/ft $*10^{-3}$	0.466 5.6	0.443 5.3	0.444 5.3	0.417 5.0	0.487 5.8	0.541 6.5

Water-reducing admixtures were simultaneously employed for the purpose of reducing the water content while maintaining the desired workability. Fly ash was used primarily as a partial replacement for cement to reduce the heat of hydration. Basic physical and mechanical properties of the mass concrete are shown in Table 6.

It is apparent from the Table 6 that the mechanical properties of pumpable mass concrete, such as compressive strength, tensile strength, flexural strength, and bond strength, containing both fly ash and water-reducing admixture are similar to those expected with water-reducing admixtures alone.

By using a conduction calorimeter, the rate of heat evolution from cement pastes during the setting and early hardening period were recorded. Table 7 shows the mixtures of cement paste for testing and its corresponding test results for cement paste heat of hydration.

Table 7: Measured Results Heat of Hydration for Cement Paste

Cement (kg/cm^3) (lb/cu.yd.)		355 599	319 537	345 580	311 524	340 572	306 516
Fly ash (%)		0	56.4	0	54.8	0	54.0
Type of Water-reducer		M	M	NF	NF	SP	SP
Mixture of Cement Paste for Testing (g)	Cement	14.2	12.7	13.8	12.4	13.6	12.2
	Fly Ash	0	2.3	0	2.2	0	2.2
	Fine Sand	0.8	0	1.2	0.4	1.4	0.6
	Water	7.8	7.8	7.8	7.8	7.8	7.8
Hydration Heat (cal/g)	24-hours	28.81	18.11	24.73	23.64	7.77	7.37
	48-hours	55.92	43.73	46.02	49.29	38.55	31.19
	72-hours	61.23	54.44	51.52	57.40	49.52	46.00
Peak Appearing Time (h)		19.5	27.0	21.0	23.0	34.0	41.5

These test results indicate that partial replacement of cement by fly ash exerted a distinct effect on reduction in the heat of hydration. The hydration heat liberated was lower and-slower than that without fly ash in the paste.

In conclusion, addition of fly ash with proper admixture in mix proportions can produce mass concrete of good workability, reduce cement content, decrease hydration heat of cement, and slow down heat release, thus ensuring quality control for the pumpable mass concrete construction

(ii) High-strength fly ash aggregate concrete [5] This was a study on the use of fly ash aggregate produced by a rotary kiln (with vertical preheater) for making lightweight aggregate concrete. A new method of mix design was adopted, which considered effects of specific surface area of fly ash aggregate on water absorption, as well as its relation with the mortar wrapping around aggregate, thereby determining the amount of mortar. A corresponding new technology of mixing was used, which specified that the total amount of mortar was divided into two batches and then mixed with fly ash aggregates one after another. The doubles mixing technology is helpful in well distributing the mortar, to wrap fly ash aggregates and increase the bond strength at the interface. The properties of high-strength fly ash aggregate concrete are shown in Table 8.

Table 8: properties of High-Strength Fly Ash Aggregate Concrete

Concrete Grade	50 MPa (7250psi)	60 MPa (8700psi)
Cement (kg/m^3)	405	471
(lb/cu.yd.)	683	794
Wrapping Coefficent (K)	1.28	1.25
Oven-dry Density (kg/m^3)	1830	1820
(lb/ft^3)	114	114
Compressive Strength (MPa)	55.4	62.8
(psi)	7880	8930
Flexural Strength (MPa)	6.61	6.91
(psi)	940	985
Splitting Tensile Strength (MPa)	2.88	3.26
(psi)	410	465
Modulus of Elasticity (MPa)	$2.43 \cdot 10^4$	$2.53 \cdot 10^4$
(psi)	$3.46 \cdot 10^6$	$3.59 \cdot 10^6$
Strength loss after 25 cycle of freezing and thawing (%)	8.3	9.1
Thermal Conductivity (w/m.k)	0.7707	0.8297

As shown in Table 8, the physical and mechanical properties, and cement demand for the lightweight concretes, which were prepared according to the new mix design and new mixing technology, were similar to those of ordinary concretes of the same grade.

CONCLUSIONS

Fly ash previously was thought of as solid waste, but through scientific research and application technique it can be turned into raw material for engineering material. Utilization of fly ash as admixture for walling material in residential buildings not only reduces urban environmental pollution but also lowers its construction cost. In Shanghai alone, savings on building materials and construction costs due to the use of fly ash has exceeded 50 million Yuan (RMB) (US S 10 million) in the past over 20 years.

Fly ash admixed in the concrete not only replaces a certain amount of cement and substitutes for a certain amount of fine aggregates, but also improves workability, reduces heat of hydration and density, increases impermeability and final strength of concrete. Besides being used in ordinary concrete, fly ash is especially suitable for mass concrete, pumped ready-mixed concrete, and even high-strength concrete. At present, in Shanghai alone at least 60,000 tons of fly ash is used yearly as admixture in concrete.

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