Application of GGBS in China

-A Gradual Shift From Cost-Savings To Durability

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Abstract

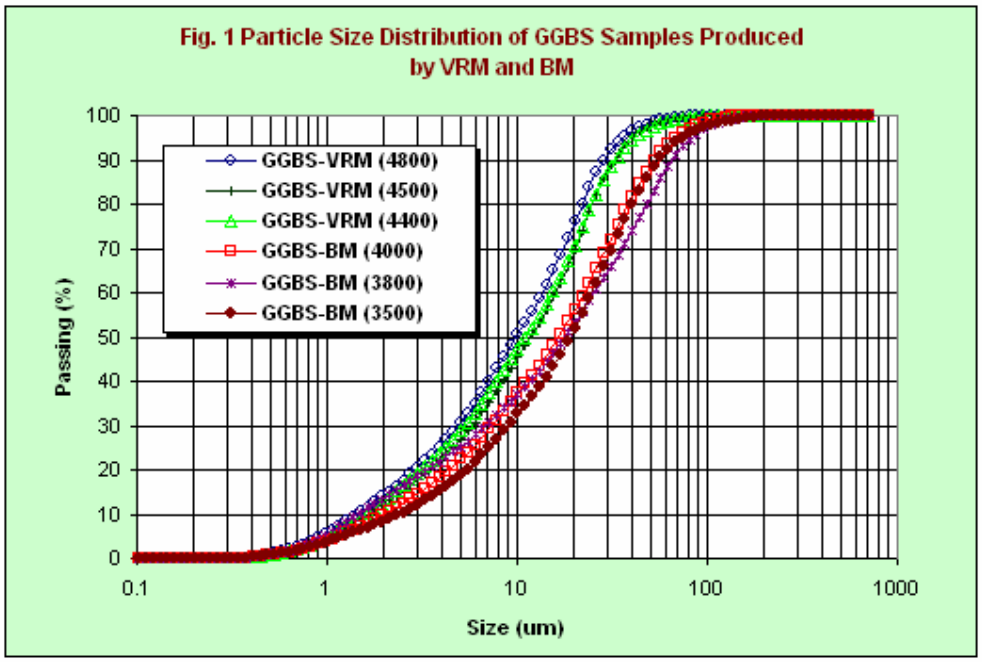
In China, quality Ground Granulated Blastfurnace Slag ("GGBS") (S95, baline 4200-4500cm^2/g) produced with vertical roller mills are being used to substitute clinker in conventional cement manufacturing as well as to partially replace OPC for ready-mixed concrete production, for which the percentage of GGBS usage is typically at 10%-15% and 20%-25% respectively. Such low percentage of GGBS in the mixing ratio, however, whilst achieving the purpose of saving some costs, is insufficient in enhancing concrete structural durability. A long journey remains ahead for the newly established slag grinding industry to reach the day when all the inherent qualities of GGBS and its superior characteristics over fly ash or other pozzolanic materials are fully appreciated

1. Introduction

This paper touches on GGBS with blaine ranging 4200-4500 cm^2/g, complying with GB/T 18046 S95 and produced ideally with the state of the art equipment -Vertical Roller Mill ("VRM"). Compared with GGBS produced by ball mills ("BM"), which is at typical blaine of 3800-4000cm^2/g, VRM-produced GGBS is very much superior in terms of fineness, production efficiency, cost-effectiveness, product reactivity and its applications. Regardless of the chemical composition, significant differences between VRM GGBS and BM GGBS are with blaine fineness and particle size distribution (see Table 1 and Figure 1).

Table 1. Particle Size Distribution of GGBS Samples Produced by VRM and BM

GGBS Samples	GGBS-VRM 4800	GGBS-VRM 4500	GGBS-VRM 4400	GGBS-BM 4000	GGBS-BM 3800	GGBS-BM 3500
Blaine (cm^2/g)	4800	4500	4400	4000	3800	3500
D_{50} (μm)	10	11	11	17	19	20
D_{75} (μm)	20	21	22	34	44	37
D_{90} (μm)	29	30	34	52	67	57
D_{100} (μm)	88	74	105	148	176	209



2. Development of GGBS Production in China

China has witnessed a rapid growing rate in slag grinding and production of quality GGBS has been seen literally across the country since the mid-1990s, credit being given to the eco-friendly economic development policy adopted by the central government for the steel industry and the increased awareness and recognition of the benefits on the use of quality GGBS not only by cement manufacturers and ready-mixed concrete players, but also by real estate developers, architects and designers and the public. With the establishment of the national standard GB/T 18046 announced in year 2000, market demand for quality GGBS has been given a big boost.

2.1 The 1st VRM Was In Operation In Shanghai by 1997

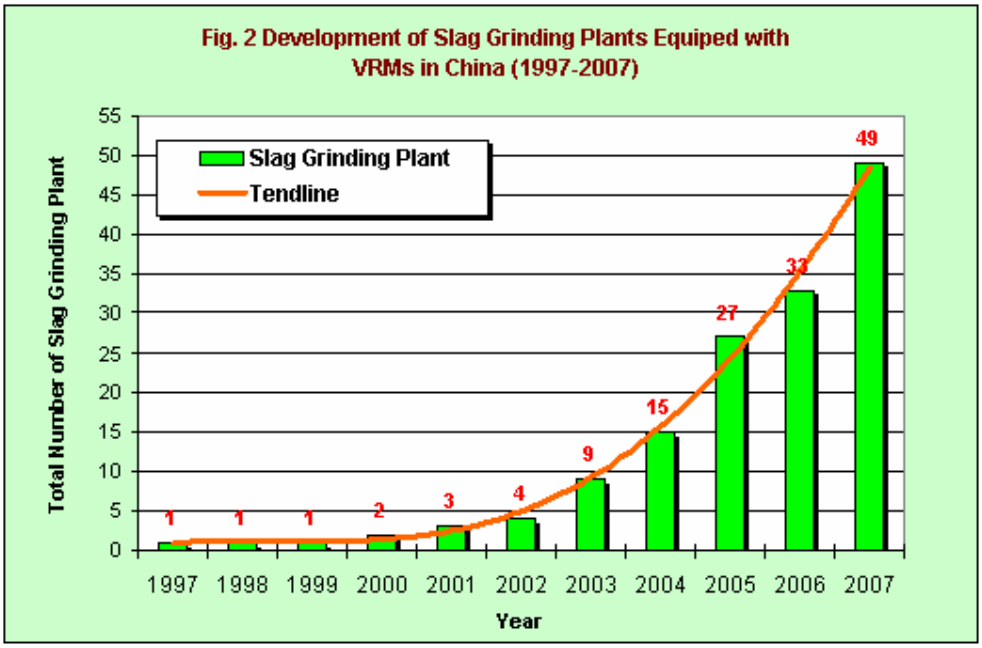
1997 marked the first milestone in the rather short history of quality GGBS production in China when commercial operations of its 1st modern slag grinding plant (with design capacity 500,000tpa) began in Baosteel of Shanghai. Since the birth of this 1st VRM for slag grinding in China, quality GGBS has been commercialized successfully and most rapidly in China.

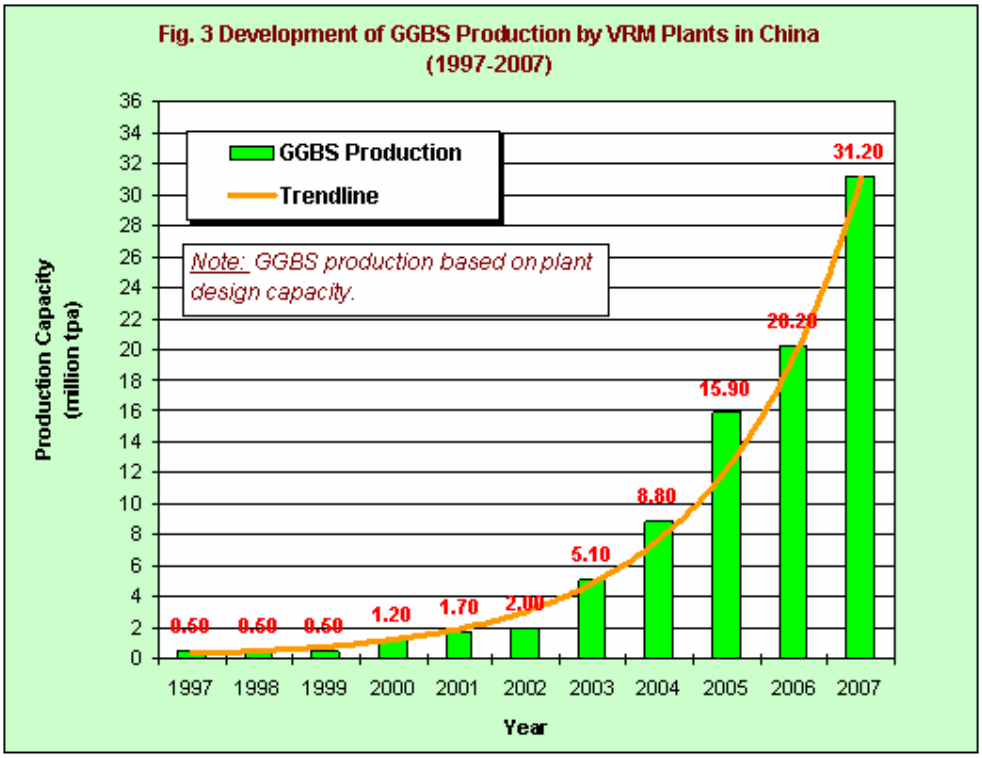
2.2 Development of GGBS Production Has Been Accelerated Over The Last Decade

Figure 2 shows the number of slag grinding plants set up in China over the last decade. Between 1997 when the 1st VRM GGBS plant was set up at Baosteel, Shanghai and the end of 2007, the number of operating slag grinding plants has increased from 1 to a projected 49. Out of the 49 GGBS plants, about 45 plants were set up over the 5-year period. from 2002 to 2007. This rapid growth trend has resulted in China being the largest market for relevant grinding mills technology for the next 3 to 5 years.

A correspondingly rapid uptrend in GGBS production since 2002 is shown in Figure 3. Within a mere 10 years from the time when the 1st VRM came into being in China, the total GGBS production has gone from a zero position to an amazing projected 31.2 million tons per annum by end of 2007, a figure

likely to be the highest in the world for GGBS produced by VRMs [2].





2.3 Slag Grinding Becomes An Industrial Sector Independent From Cement Industry

Compared with other countries, a unique phenomenon has emerged in that slag grinding industry has become a sector to be reckoned with, independent from the cement industry. Table 2 shows the projection that about 65% or 20 million tons of GGBS is to be produced by non-cement related

manufacturers in China by 2007.

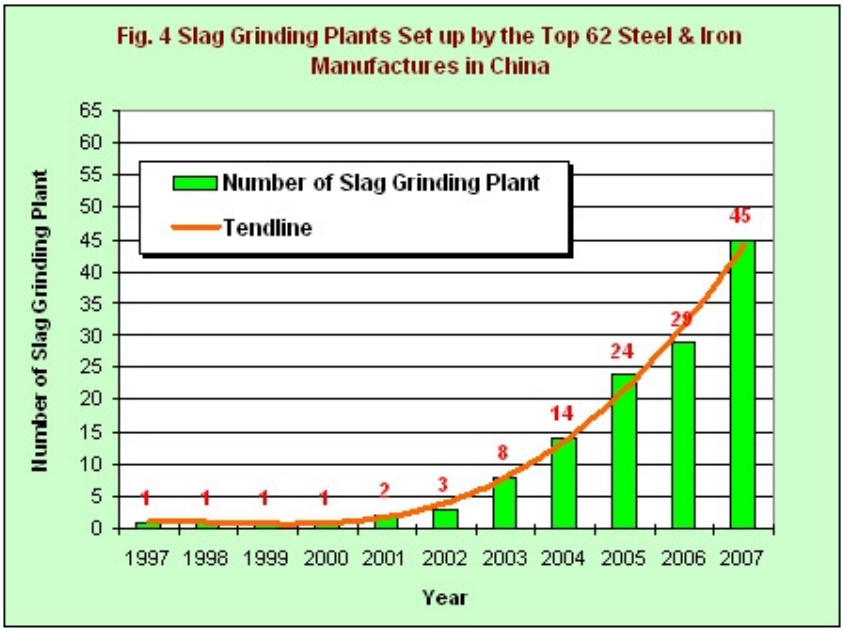
Table 2 Slag Grinding Plants Run by Non-cement Manufactures in China (projected by year 2007)

Slag Grinding Plant	Number	%	Output (million tpa)	%
Plant run by Cement Manufacture	16	33	10.80	35
Plant run by Non-cement Manufacture	33	67	20.40	65
Total (projected by 2007)	49	100	31.20	100

2.4 Continuous Expansion of Slag Grinding Plants Foreseen In Next 5 years

As reported [3], China's top 62 steel mills produced a total of 277.63 million tons of pig iron in 2005, accounting for 86% of the total pig iron production of the whole country. This figure is projected to be 299.84 million tons for 2006 (accounting for 84% of the total amount produced by the country). Therefore, based on a very conservative estimate, total raw slag generated by these 62 steel mills in 2005 is approximately 83.29 million tons, and this figure is projected to be around 89.96 million tons for 2006. Due to the rather high investment capital required for each VRM slag grinding plant, (average costs for a plant with 600,000tpa designed capacity is approximately Rmb 90 million), in order that a reasonable return on investment may be realized, it is almost a prerequisite that the plant is supported by a steel mill generating at least 300,000 tpa of slag.

As shown in Figure 4, there will be a total of 45 slag grinding plants in operation among the top 62 steel mills in China by year-end of 2007. By then, about 73% of the top 62 steel mills will have either their wholly owned or associated companies engaged in slag grinding and together producing up to 29.9 million tpa GGBS (i.e. utilizing about 36% of the raw slag generated by this group in 2005). Therefore, expansion of slag grinding capacity in China is expected to continue at least for the next 5 years if the huge slag resources are to be fully utilized to churn out high quality and value-added GGBS.



3. Application Of GGBS In China

3.1 Two Main Usages Of GGBS With Cement Producers Being Top Consumers

Taking the path experienced in other countries, China has used its increased amount of GGBS mainly as (a) clinker substitution in blended slag and normal cement production, and (b) supplementary cementitious material in ready-mixed and site-batched concrete production. At present, benefits derived from costs reduction is the direct and key driving force for the adoption of GGBS.

Further investigation shows that cement manufactures in China are projected to produce a total of about 10 million tpa of GGBS in 2007, which amount is nearly fully used consumed by the cement plants in the production of slag cement, incorporating properly designed and efficient cement mixing equipments. Typical blended slag cements produced are P.S 42.5 and P.S 32.5 (complying with GB 1344) with GGBS contents of 25-35% and 50-60% respectively. It is estimated the costs of GGBS (S95) to cement producers is around Rmb 80-100 per ton (depending on the raw slag price), versus about Rmb 130-140 per ton being the costs of producing clinker. Therefore, for incorporating every one ton of GGBS, cement producers stand to make an additional profit of Rmb 30-40 which translates into 10-15% increase to the bottom line.

Where does the balance quantity of GGBS end up? They are sold to cement manufactures or concrete producers, key considerations being again savings in costs of production. Examples are given in Table 3 and Table 4 on how the cement and concrete producers generate additional profits through the use of GGBS (separate product).

In accordance with the geographical location of each slag grinding plant and its market coverage (within 150-200km radius), GGBS markets can be categorized into three, i.e. 1st-tier city, 2nd-tier city and 3rd-tie city. Table 5 shows the projection of GGBS quantity to be shared by the above three market categories in China by year 2007.

According to market information collected, it is found that due to the huge difference in macro economic development among the above 3 different tiers of city, the use of GGBS is also entirely different. Table 6 gives the projection of GGBS to be used in cement and concrete production in each market.

Table 3 Increased Profit Made by Use of GGBS in Cement Production

Case 1- A cement plant with throughput of 1.2 million tpa P.O 42.5 with rotary kiln clinker

Cement Product	Cement Selling Price (Rmb/t)	Throughput (million tpa)	GGBS Price at delivery (Rmb/t)	Substitution of Cement (%)	GGBS Usage (million tpa)	Total Throughput (million tpa)	Increase in Profit (million Rmb pa)
P.O 42.5	230	1.20	160	**10**	0.12	1.32	**8.4**

Case 2 - A cement plant with throughput of 0.4 million tpa of P.O 32.5 with vertical shaft kiln clinker

Cement Product	Cement Selling Price (Rmb/t)	Throughput (million tpa)	GGBS Price at delivery (Rmb/t)	Substitution of Cement (%)	GGBS Usage (million tpa)	Total Throughput (million tpa)	Increase in Profit (million Rmb pa)
P.O 32.5	200	0.40	160	**20**	0.08	0.48	**3.2**

Note : Cement plants quoted are operating in Tangshang city, Hebei Province of China (March 2006).

Table 4 Cost-Saving Made by Use of GGBS in Ready-Mixed Concrete Production
(C30 Pump, typical mix design)

Markets in China	Cementitious Material	Unit Price (Rmb/t)*	Control Mix (kg/m^3)	GGBS 20% (kg/m^3)	GGBS 25% (kg/m^3)	GGBS 30% (kg/m^3)	GGBS 35% (kg/m^3)
Beijing	Cement P.O 42.5	305.00	300	240	225	210	195
	GGBS (S95)	190.00	0	60	75	90	105
	Fly Ash (glade I)	140.00	88	88	88	88	88
	Cost-saving (Rmb/m^3)		**0.00**	**6.90**	**8.63**	***10.35***	***12.08***
Tianjin	Cement P.O 42.5	300.00	310	248	233	217	202
	GGBS (S95)	180.00	0	62	78	93	109
	Fly Ash (glade II)	75.00	80	80	80	80	81
	Cost-saving (Rmb/m^3)		**0.00**	***7.44***	**9.30**	***11.16***	***13.02***
Shanghai	Cement P.O 42.5	320.00	300	238	225	210	195
	GGBS (S95)	205.00	0	62	75	90	105
	Fly Ash (glade II)	110.00	80	80	80	80	80
	Cost-saving (Rmb/m^3)		**0.00**	***7.13***	**8.63**	***10.35***	***12.08***
Chongqing	Cement P.O 42.5	305.00	300	238	225	210	195
	GGBS (S95)	230.00	0	62	75	90	105
	Fly Ash (glade II)	110.00	80	80	80	80	80
	Cost-saving (Rmb/m^3)		**0.00**	***4.65***	**5.63**	***6.75***	***7.88***

Note : Delivery prices in the local markets in August 2006.

Table 5 Categorization of Markets for GGBS (Separate Product) in China (projected by year 2007)

Market Category by Cities*	1st-tier cities		2nd-tier cities		3rd-tier cities		Total
	(million tpa)	%	(million tpa)	%	(million tpa)	%	(million tpa)
GGBS Output (by 2007)	5.50	27	8.90	44	6.00	29	20.40

Note : 1st-tier cities are the four capital cities of China, i.e. Beijing, Shanghai, Tianjin and Chongqing. 2nd-tier cities are the provincial capital cities and those medium cities located in coastal developed economic zones. 3rd-tier cities are medium cities located further inland.

Table 6 GGBS Used in Cement and Concrete Productions in Different Markets in China (projected by year 2007)

Market Category		1st-tier cities		2nd-tier cities		3rd-tier cities		Total	
		Cement	Concrete	Cement	Concrete	Cement	Concrete	Cement	Concrete
GGBS Output (by 2007)	(%)	10	90	70	30	85	15	58	42
	(million tpa)	0.55	4.95	6.23	2.67	5.10	0.90	11.88	8.52

Therefore, by 2007, there will be about 42% (or 8.52 million tons) of GGBS available to concrete players, with the balance 58% (or 11.88 million tons) going into cement production. Our further investigation suggests that due to the constraint of efficient mixing facilities, cement plants which are buying GGBS from local markets are using it for producing P.O 42.5 and or P.O 32.5 at an average mixing ratio of 15% (see Table 3). This figure is about half of what is being used for slag cement

production at cement mixing plants which are using their own-produced GGBS.

The total amount of GGBS used for cement production in China in 2007 is projected to account for 73% of total production, equivalent to 22.68 million tons (i.e. the sum total of 11.88 million tons produced by non-cement producers and 10.8 million tons produced by cement producers). The balance 27% or 8.52 million tons of GGBS will be used for concrete production at a typical ratio of 25%-30% (replacing 80-90kg cement per cubic meter in design mix) by the whole country.

3.2 Durable Concrete Requires High Percentage Mixture of GGBS

There is no doubt that GGBS is now recognized worldwide as a green construction material capable of producing durable concrete structures. Apart from cost reduction the most important technical benefits, which GGBS imparts to concrete, include:

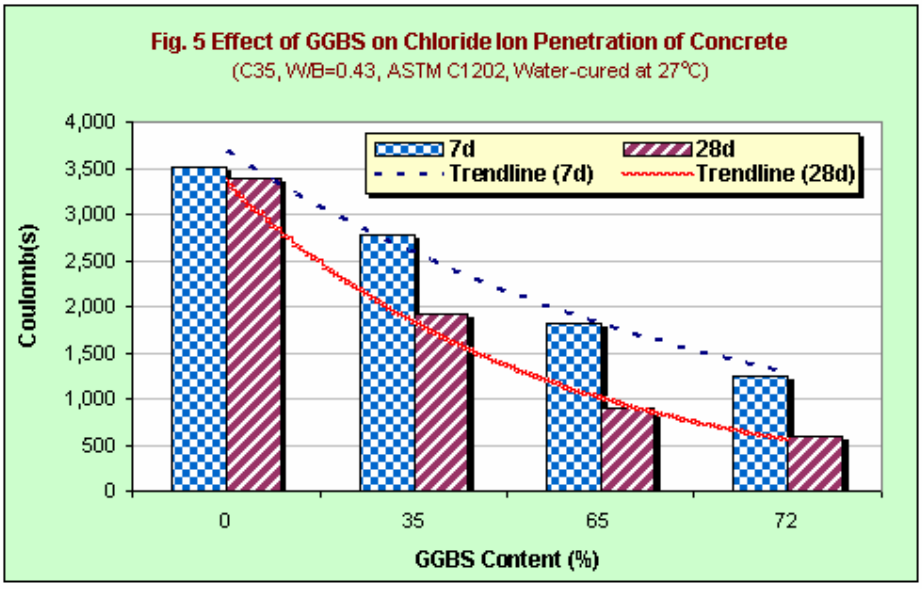
(a) Lower temperature rise in concrete, reducing the risk of thermal cracking in massive concrete structures.

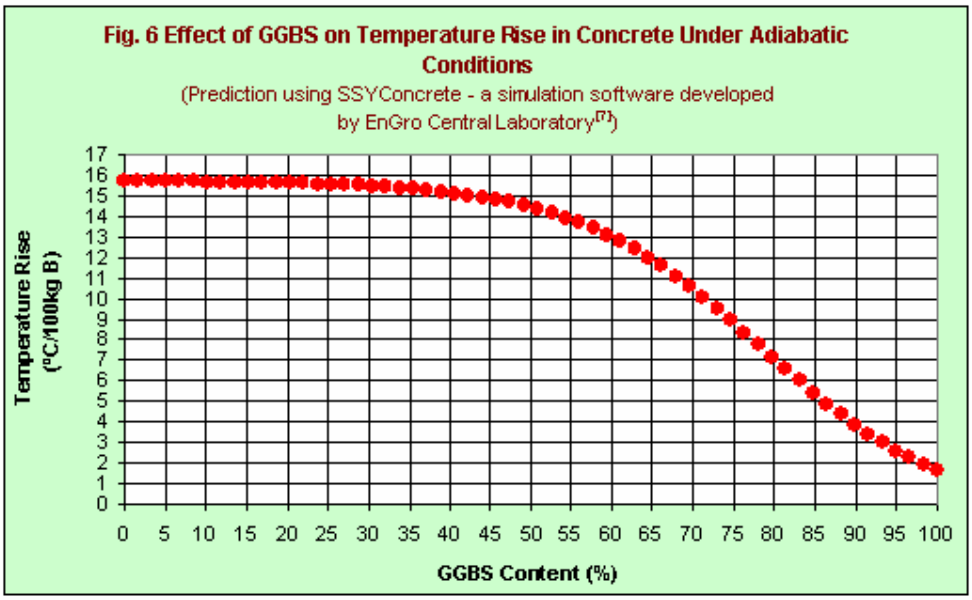
(b) Elimination of the risk of damage caused by Alkali-silica Reaction (ASR).

(c) High resistance to chloride ingress, reducing the risk of reinforcement corrosion.

(d) High resistance to attacks by sulphate and other chemicals.

Extensive applied studies over the many projects conducted globally prove that in order to produce high performance concrete (HPC) structures with desired durability and satisfactory strength, 'adequate' GGBS percentage is essential[4]. For the applications where durability is required, a 55%-65% GGBS content (in combination of OPC) is generally recommended[5] or, a higher dosage of 70%-85% has been specified for structures subject to severe environment[6]. Same observations were found in our studies on GGBS sample from Tangshan Tanglong Materials Comp. Ltd, China (see Figure 5 and Figure 6).





3.3 Delay In Specification Of Unified National Standard And Misconception Slowed Down The Shift Of Emphasis In Use Of GGBS From Cost-Savings To Durability In China

The 1st job reference reported using GGBS (ball mill product with blaine about 4000cm^2/g) for concrete durability was successfully done in 1996 at Beijing airport extension project, in which about 60% GGBS was used to prevent the raft foundation from thermal-cracking[8]. This represented a breakthrough of GGBS application in China because prior to this there was no specification allowing the use of GGBS in concrete. Three years later (i.e. in 1999) the 1st local practice code for application of concrete with GGBS (DG/TJ08-501-1999) was set up in Shanghai, China. Since then GGBS has been widely used in concrete production, particularly for the benefits of both cost reduction and durability within the city. Following Shanghai, Beijing established its own local specification namely Applied Technical Specification of Mineral Admixtures in Concrete (DBJ/T01-64-2002) in 2002, in which GGBS as one type mineral admixture is officially allowed to be used for concrete production. As a result, usage of GGBS in concrete production maintains very high percentage in both capital cities exclusively in China.

However, in most of the other cities in China, the fact is that use of GGBS in concrete production has not been officially announced to be permissible even as of the time of writing. Most of the concrete suppliers in these cities would not put GGBS even in the mix design proposal, though in actual fact it is widely known that they frequently do eventually adopt 20%-30% GGBS as cement replacement which is, however, not disclosed when they submit to the owner or consultant of the project for approval, since they are fully aware that if they disclose the truth, the owner or consultant will not give their approval due to the lack of relevant national technical guidelines to support the same. Therefore, this situation will continue until a national specification for making durable concrete structures is available. For this reason, no accurate or official data of GGBS used for making durable concrete structures (or high performance concrete) are available in China. It is, however, generally estimated that this sector accounts for about 5%-8% of the total GGBS output.

As compared to the fast growth of GGBS production, the transition of emphasis on the GGBS

applications from one of cost-saving to concrete durability has proven to be a much slower process. Constraints encountered by the industry are:

(a) (from national level) delay in establishing unified national standards and technical guidelines for use of GGBS in durable concrete structures, and

(b) (from the public) misconception on GGBS as a low grade replacement material (this could well be true in the case of traditional BM GGBS which is of very low fineness, but not if GGBS is produced by VRM).

In fact, changing the public's misconception on GGBS being a by-product from steel and iron production and, hence, a replacement material of low quality which is therefore not conducive to high quality mineral admixture for producing high performance concrete, will take even longer time than the setting up of a national standard. This poses a real challenge ahead for the construction industry in China.

4. Concluding Remarks

（1） Development of quality GGBS production with VRMs has been experiencing an accelerated growing rate since 1997 in China. It is projected to have 49 modern slag grinding plants in operation, which will produce 31.2 million tpa in total by end of 2007. China slag grinding industry is now becoming a stand alone industry sector independent from cement industry.

（2） Continuous expansion of existing slag grinding plants is foreseen in China in the next at least 5 years in order to maximize the utilization of its huge raw slag resource for producing high quality and value-added product of GGBS.

（3） China has used its increased availability of GGBS mainly as clinker substitution in cement production and supplementary cementitious material in concrete production (accounting for 73% and 27% of the total GGBS output respectively). At the present time, benefits from cost reduction is the direct and key driving force for the use of GGBS.

（4） Due to the lack of unified national standards and technical guidelines for use of GGBS in durable concrete structures very low amount or 5%-8% of the total GGBS output is estimated to be used for concrete production especially due to requirement of durability in 2006 and 2007.

（5） Misconception of GGBS being a low grade replacement material used for cost-saving by cement or concrete suppliers is a major barrier in GGBS being acknowledged and used for durability purpose in China. It slows down the change in perception of its key value from cost-saving to durability in China. Education to all concerned is the only answer to this unfortunate situation.

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