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Indian cements produced in MVR- and MPS-mills – impact of composite material properties

In Indien auf MVR- und MPS-Mühlen hergestellte Zemente – Einfluss der Eigenschaften der weiteren Hauptbestandteile

C. Woywadt, B. Henrich, Gebr. Pfeiffer SE, Kaiserslautern, Germany

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C. Woywadt, B. Henrich, Gebr. Pfeiffer SE, Kaiserslautern, Germany

SUMMARY

Production of composite cements in India has been very common for many decades, the amount of composite cements is still increasing considerably from 36 % in 2000/2001 to more than 75 % nowadays. Due to the great differences in the properties of the main composites such as granulated blast furnace slag (GBFS) and fly ash, the technology of manufacturing composite cements is rather complex. This paper will discuss the physical and chemical properties of GBFS and fly ash. The results will be discussed for the biggest mill MVR 6700 C-6 installed in Brazil for the production of slag cements with different proportions of slag as well as the results of Indian installations of MVR and MPS mills producing composite cements.

ZUSAMMENFASSUNG

Die Produktion von Kompositzementen ist in Indien seit vielen Jahrzehnten weit verbreitet mit weiterhin steigendem Anteil von 36 % in den Jahren 2000/2001 auf über 75 % bis heute. Aufgrund der großen Unterschiede in den Eigenschaften der wichtigsten Zementhauptbestandteile wie Hüttensand (GBFS) und Flugasche, ist die Technologie zur Herstellung von Kompositzementen recht komplex. In dem Beitrag werden die physikalischen und chemischen Eigenschaften von GBFS und Flugasche diskutiert. Es werden Betriebsergebnisse von der größten in Brasilien installierten Mühle MVR 6700 C-6 zur Herstellung von Hochofenzement mit unterschiedlichen Hüttensandanteilen diskutiert ebenso wie Ergebnisse aus indischen Installationen von MVR- und MPS-Mühlen zur Herstellung von Kompositzementen.

(English text supplied by the authors)

Indian cements produced in MVR- and MPS-mills – impact of composite material properties*)

In Indien auf MVR- und MPS-Mühlen hergestellte Zemente – Einfluss der Eigenschaften der weiteren Hauptbestandteile*)

1 Introduction

India is home to 1.2 billion people, a fast growing economy and a vibrant business community, coupled with severe poverty, rapid urbanization, water stress and limited energy access [1]. However, the cement industry must meet manifold requirements in terms of sustainable development. The Low Carbon Technology Roadmap 2050 reflects the considerable importance of topics like alternative fuels and raw materials, thermal and electrical energy efficiency, clinker substitution and new products as well as waste heat recovery.

As a partner of the cement manufacturers, Gebr. Pfeiffer SE offers support in dealing with these issues by addressing topics and tackling tasks relating to mill operation and optimized product properties. In terms of sustainable development cement producers must meet versatile requirements; a special key concern is, as well as power consumption and plant availability, the substitution of clinker. The new technology of the MVR mill, available on the market for the past ten years, is the right choice for increased plant availability and ease of maintenance combined with low specific electric and thermal energy consumption.

Production of composite cements in India has been very common for many decades, the amount of composite cements is still increasing considerably from 36 % in 2000/2001 to more than 75 % nowadays. The production of Ordinary Portland Cement in India currently remains at about 25 % and that of Portland Pozzolana Cement has steadily increased to about 67 %. The production of Portland slag cement is limited to 8 %. The production trend of different types of cement such as OPC-, PPC-, PSC and others in recent decades indicates that the trend is more towards blended cements. This is a favorable change in the product mix of the Indian cement industry as PPC- and PSC-cements are more specialized types with advantages in terms of better durability characteristics [2].

Due to the great differences in the properties of the main composites such as granulated blast furnace slag (GBFS) and fly ash, the technology of manufacturing composite cements is rather complex. This paper will discuss the physical and chemical properties of GBFS and fly ash. Laboratory and pilot plant results on grindability and reactivity of Indian GBFS from different sources will be described. The fineness of Indian fly ashes varies in a wide range, the results comparing the particle size distribution and their impact on vertical roller mill operation will be discussed.

Operational results of MVR vertical roller mills for grinding composite cements will be highlighted in detail. The results will be discussed for the biggest mill of the type MVR 6700 C-6 installed in Brazil for production of slag cements with different proportions of slag as well as the results of Indian installations of MVR and MPS mills producing composite cements.

2 Technology roadmap – Indian cement industry

The Indian cement industry is the second-largest in the world, after China. Total installed capacity was about 320 million t in 2010. Kiln capacities cover up to 13 500 t/d, whereas the average capacity rate is 4 500 t/d. At present, the cement industry is the third-largest energy consumer and second-largest CO_2 emitter in India's manufacturing sector. About 50 % of capacity has been installed in the last ten years, almost 99 % of the installed capacity in India uses dry process manufacturing [3]. By adopting the best available technologies and environmental practices the total CO_2 emissions have been reduced from 1.12 t CO_2/t cement in 1996 to an industrial average of 0.719 t CO_2/t cement in 2010.

Five topics are mainly concerned in emissions reduction: Alternative fuel and raw material, thermal and electrical energy efficiency, clinker substitution, waste heat recovery and newer technologies.

3 Clinker substitution

The Indian cement industry has been increasing the share of blended cements in its overall cement mix. In ❱ Fig. 1 the share of cement type and clinker-to-cement ratio for Indian cements is shown.

The main clinker substitutes are fly-ash and granulated blast-furnace slag. The cement type PPC is produced with fly ash as a clinker substitute that is sourced from coal-fired power

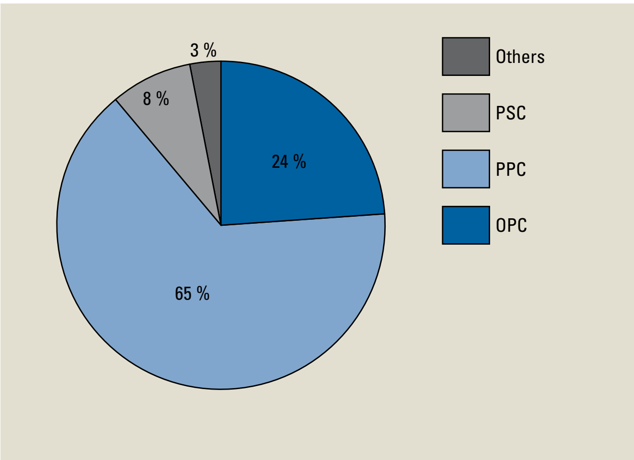

Figure 1: Share of annual production of cement types in India in 2010 [3]

*) Revised version of a lecture given by the authors at the 15th NCB International Seminar on Cement, Concrete and Building Materials in December 2017 in New Delhi, India

plants. Granulated blast-furnace slag as a by-product from the steel and iron industry is well proven as a substitute and is interground with clinker and gypsum or is ground separately and mixed afterwards with OPC cement. Due to the great differences in the properties of the main composites such as granulated blastfurnace slag (GBFS) and fly ash the technology of manufacturing composite cements is rather complex.

4 Investigative program

4.1 Granulated Blast-Furnace Slag (GBFS)

Vitreous solidification is a precondition for the latent hydraulic behaviour of the granulated blast-furnace slag and therefore for its use as a main constituent of cement or as a reactive concrete addition. The engineering properties of granulated blast-furnace slag, including its dewatering and transport characteristics, its tendency to consolidation, its grindability and, naturally, its reactivity are determined by its physical and chemical properties [4].

Indian GBFS from ten different sources were investigated with regard to grindability and reactivity at the Gebr. Pfeiffer test center. Physical properties such as magnetic content, bulk density and particle size distribution as received as well as the chemical composition by XRF were determined. ❱ Table 1 shows the results for the physical properties of the received slag samples.

The figures show a wide variation in residue on 2 mm from 3.1 % up to 22.0 %. The magnetic content varies between 0.1 to 1.8 %. The bulk density – known as a measure of grindability (the lower the bulk density the better the grindability) [5] – varies from 0.62 to 1.21 kg/l. Pictures of the GBFS samples as delivered are shown in ❱ Fig. 2.

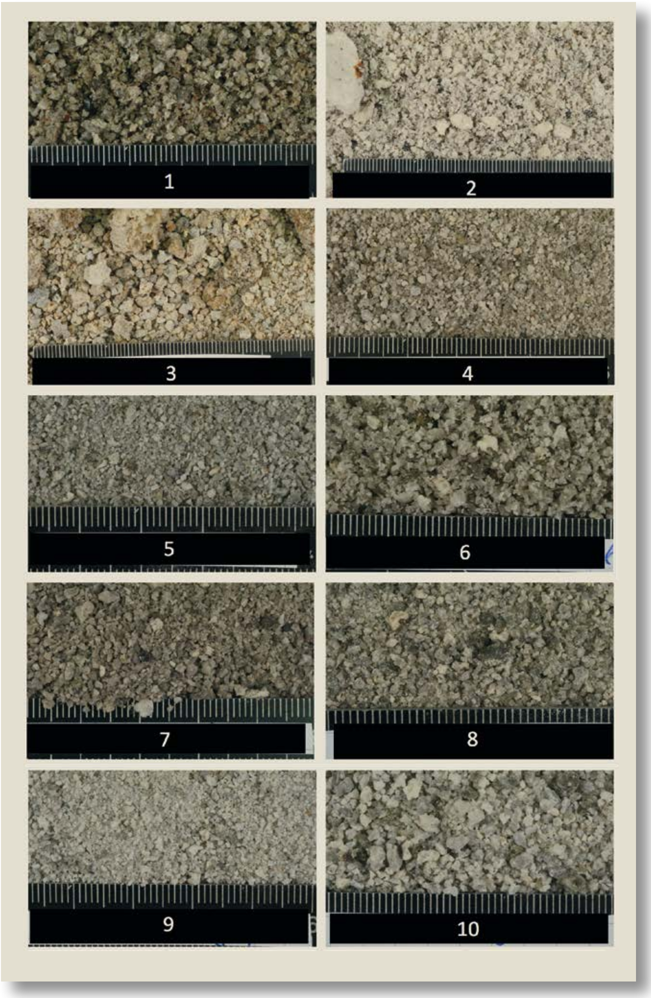

Figure 2: GBFS samples from different sources

Table 1: GBFS samples-physical properties

GBFS	Unit	1	2	3	4	5	6	7	8	9	10
R0,5 mm	%	91.9	76.2	95.8	76.5	73.1	84.1	74.6	66.3	54.9	83.1
R2,0 mm	%	22.0	16.9	10.9	3.1	7.6	12.1	5.7	4.9	1.7	15.9
Magnetic content	%	1.8	1.6	0.3	0.3	0.2	0.2	0.4	0.1	0.3	0.2
Bulk density	kg/l	1.05	0.62	1.04	1.17	1.16	1.08	1.21	1.14	1.10	0.99

Table 2: Chemical composition and characteristical values of the GBFS used

Compound	Unit	1	2	3	4	5	6	7	8	9	10
SiO_2	mass %	34.0	34.5	34.0	34.1	33.7	33.7	33.5	32.3	32.2	33.3
CaO	mass %	34.8	36.2	37.5	35.4	34.5	34.6	32.9	33.6	32.2	35.3
MgO	mass %	7.6	3.1	6.9	7.8	9.2	7.5	8.2	9.6	10.4	7.8
Fe_2O_3	mass %	0.8	0.8	0.5	0.7	0.6	0.5	0.9	0.5	0.5	0.5
Al_2O_3	mass %	19.0	21.5	15.7	18.8	18.9	18.8	19.3	19.7	20.4	19.3
TiO_2	mass %	0.6	0.6	0.7	0.7	0.7	0.6	0.7	1.0	0.7	0.7
SO_3	mass %	0.7	0.7	0.6	0.6	0.8	0.5	0.8	0.7	0.6	0.6
LOI	mass %	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
$CaO+MgO+SiO_2$	mass %	76.4	73.8	78.4	77.3	77.4	75.8	74.6	75.5	74.8	76.4
CaO/SiO_2	–	1.03	1.05	1.10	1.04	1.02	1.03	0.98	1.04	1.00	1.06
$(CaO+MgO)/SiO_2$	–	1.25	1.14	1.31	1.27	1.30	1.25	1.23	1.34	1.32	1.29

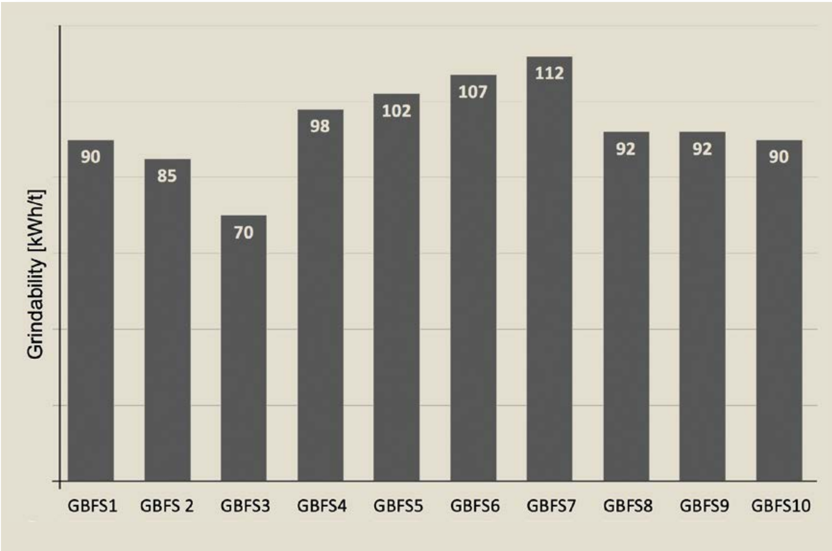

Figure 3: Grindability of different GBFS to a fineness of 4000 cm²/g Blaine, ground in a lab ball mill

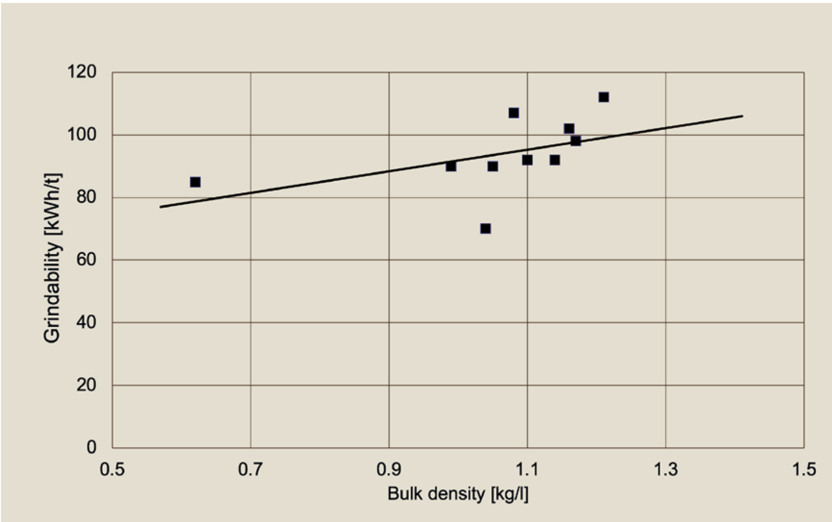

Figure 4: Grindability of GBFS depending on bulk density

Characteristic GBFS values based on chemical composition [6] are the simple basicity CaO/SiO_2 that should be greater than 1.0. In accordance with DIN EN 15167 the term $CaO+MgO/SiO_2$ should be greater than 1.0 and the sum of Cao, MgO and SiO_2 should be greater than 2/3. ❱ Table 2 shows the chemical properties and characteristic GBFS slag values based on chemical composition for the ten GBFS samples.

One important question in the assessment of the chemical properties is whether and how the above-mentioned characteristic values correlate with the mortar properties. Therefore, the received GBFS were ground in a lab ball mill to determine the grindability and to produce GGBFS to test the reactivity in accordance to EN 15167 (Paragraph 5.3.2.3).

❱ Fig. 3 shows the grindability (lab ball mill equivalent to an open circuit ball mill) at a fineness of 4000 cm²/g Blaine. ❱ Fig. 4 shows clearly the correlation between bulk density and grindability as one specific property of GBFS.

The activity index as a measure of the reactivity of GBFS has also been determined in accordance to EN 15167. In this standard the requirements for ground GBFS are defined for use as a concrete addition. A 50 mass % OPC cement with 50 mass % ground GBFS were mixed together. The strength development of this mixture is compared to that of the pure OPC cement. The ratio of the strength of mixture to the pure OPC cement is the so-called activity index. After 28 days the strength of the mixture should be at minimum 70 mass % of the pure OPC cement. In this investigation the GBFS was ground 150 min in the lab ball mill. These samples were taken from the mixture. The results of the activity index are given in ❱ Table 3.

If the TiO_2 content exceeds a certain limit, this will lead to a loss of strength especially after 2 and 7 days depending on the basic latent-hydraulic properties of the GBFS. With the available results there is no indication of a correlation between the TiO_2-content and the strength development.

The use of GBFS is increasing worldwide for producing cements and concrete. The reaction potential is determined by many factors and parameters where the optimization depends on metallurgical and economic factors. Therefore, the issue for intergrinding or separate grinding is still in discussion. When intergrinding clinker and GBFS the finer and most reactive fractions do not contain any or only very small proportions of GBFS. The decision for the mode of grinding has to be taken carefully. The study of the ten different GBFS shows that the properties vary in a wide range and therefore, a tailor-made production mode with specific fineness of the finished product is necessary to get the required final product.

4.2 Fly ash

The utilization of fly ash as a cement replacement material in concrete or as an additive in cement introduces many benefits from economical, technical and environmental points of view. Depending on the burning temperature, coal type and some other factors, fly ashes show different properties in different size fractions. Fly ash is used in the manufacturing of PPC cement (up to 35 mass %) due to the pozzolanic action leading to a contribution towards strength development. The level off performance of fly ash depends on e.g. the lime reactivity, the carbon content and the fineness.

Table 3: Activity indices of GBFS samples

GBFS	Unit	1	2	3	4	5	6	7	8	9	10
Activity Index 28 d	%	107	110	94	114	108	101	89	106	119	108

Table 4: Physical properties of fly ash and pond ash

Designation	Unit	Fly ash	Fly ash	Fly ash	Pond ash	Pond ash	Pond ash
Moisture	%	0	0	0	24.40	22.3	27.50
Blaine value	cm²/g	7800	3400	7200	n.a.	n.a.	n.a.
R45	%	15.3	32.5	27.0	83.6	87.9	85.8

The diagram (❱ Fig. 5) and ❱ Table 4 show the particle size distribution and parameters such as the Blaine value and the residue on 45 µm of several fly ashes.

The fineness of Indian fly ashes varies in a wide range. Mechanical activation of fly ash can be done by grinding or by fractionation. Many studies about this issue have been published [7].

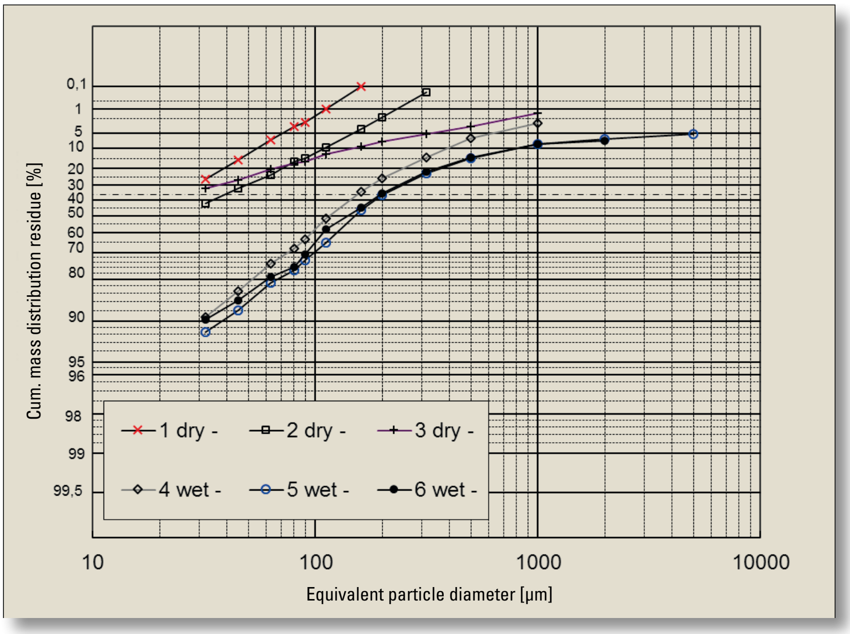

Figure 5: PSD curves of different fly ashes

5 Operational results for cement production in vertical roller mills

❱ Table 5 shows the results of OPC-, PPC- and PSC-cements ground in a MVR mill. The mills are installed in fully-integrated plants as well in grinding terminals. Therefore, different pre-conditions of feed materials have to be considered, for example clinker temperature and feed moisture of clinker substitutes etc.

The results show that all required cement qualities can be produced in vertical roller mills. The combination of drying, grinding and separation in one system is advantageous, especially when it comes to clinker substitutes. A smooth and stable mill operation with reduced water spray is possible, hence grinding without external heat is depending on feed moisture of the material possible. In all Pfeiffer mills which are installed in India the performance guaranteed could be achieved easily. The clinker temperature impacts the process conditions: if the temperature is low or ambient the amount of water spray has to be lower to fulfil the thermal process balance. With a higher clinker temperature the amount of water injection or feed moisture can be higher. In the case of layout of a grinding terminal the installation of an external heat source is recommended even when starting the plant with the production of OPC or PPC cements with dry fly ash only, because wet additives might be used in future.

The biggest mill so far with an installed power of 11500 kW on the main drive is in operation in Brazil. This mill with the designation MVR 6700 C-6 produces PSC cements with different GBFS proportions of up to 50 mass %. The civil works as well as the mechanical and electrical installation were finished in September 2015. Hot commissioning took place in April 2016. ❱ Table 6 shows the operating data achieved during the performance test.

The flexibility of the equipment allows the production of an OPC cement up to a fineness acc. to Blaine of 5500 cm²/g, which was not defined in the project. The mill operates with a smooth level of vibration. The plant was running the mill

Table 5: Cement produced in MVR mills of the type MVR 6000 C-6 installed in India

Designation	Unit	OPC	PSC	PPC	GBFS
Clinker	mass %	90	46	57	–
Gypsum	mass %	8	4	5	5
Fly ash wet/dry	mass %	2/-	–	7/31	–
GBFS	mass %	–	50	–	95
Clinker temp.	°C	135	ambient	ambient	n.a.
Feed moisture	%	1.1	6.1	0.8	11.0
Throughput	t/h	311	235	424	174
Fineness acc. to Blaine	cm²/g	2840	3830	3940	4500
Spec. energy cons. mill drive	kWh/t	17.7	25.1	13.9	35.0

Table 6: Operating data for slag cements produced in a vertical roller mill MVR 6700 C-6

Parameter	Unit	40 mass % slag 3 mass % limestone	34 mass % slag 9.5 mass % limestone	20 % slag 2 % limestone
Throughput	t/h	410	456	355
Spec. energy cons. (mill coupling)	kWh/t	26.2	23.4	27.3
Feed moisture	%	2.9	3.2	1.9
Fineness				
Blaine	cm^2/g	4600	4420	4850
R38µm	%	5.2	–	2.1
R45µm	%	–	4.5	–

without the supplier's supervisor after 79 hours of commissioning. The flexibility to operate with less than six rollers or less than six drives is given due to the drive-concept of active redundancy [8].

6 Final remarks

The use of GBFS is increasing worldwide for producing cements and concrete. The reaction potential is determined by many factors and parameters where the optimization depends on metallurgical and economic factors. Therefore, the issue for intergrinding or separate grinding is still in discussion. When intergrinding clinker and GBFS the finer and most reactive fractions do not contain any or only very small proportions of GBFS. The decision for the mode of grinding has to be taken carefully. The study of ten different GBFS shows that the properties vary in a wide range and therefore, a tailor-made production mode with specific fineness of the finished product is necessary to get the required final product quality.

Fly ash is used in the manufacturing of PPC-cements (up to 35 mass %) due to the pozzolanic action leading to a contribution towards strength development. The level of fly ash depends on e.g. lime reactivity, carbon content and the fineness.

The MVR mill, available on the market for the past ten years, is a good choice for handling of versatile feed components. In combination with increased plant availability and ease of maintenance the MVR mill offers a low specific electric energy consumption.

LITERATURE

[1] http://wbcsdpublications.org/project/the-india-companies-act-2013-a-primer-for-wbcsd-members-with-operations-in-india/

[2] Sinha, U. S.; Bhatnagar, K.; Gupta, R.; Ali, M. M.: Quality trend in Indian cements – a decade appraisal. 13th NCB International Seminar on Cement, Concrete and Building Materials, New Delhi 2013.

[3] Low-carbon technology for the Indian cement industry. International Energy Agency (IEA), 2013.

[4] Ehrenberg, A.: Influence of the granulation conditions and performance potential of granulated blastfurnace slag; part 1: granulation conditions. ZKG International (2013) No. 1, pp. 64.

[5] Mußgnug, G.: Beitrag zur Frage der Mahlbarkeit von Hochofenschlacken, Zementschlacken und Klinkern. Zement 31 (1942) H. 17/18, pp. 183–193.

[6] Ehrenberg, A.; Israel, D.; Kühn, A.; Ludwig, H.-M.; Tigges, V.; Wassing, W.: Granulated blastfurnace slag: Reaction potential and production of optimized cements; part 2. CEMENT INTERNATIONAL 6 (2008) No. 03, pp. 82–91.

[7] Chaturvedi, K.; Yadav, D.; Chatterjee, V. P.; Pahuja, A.: Activation of fly ashes for enhancing their utilization in cement manufacture. CEMENT INTERNATIONAL (2015) No. 5, pp. 62–69.

[8] Hoffmann, D.; Schmitt, L.: The multiDrive® – a safeguard against total failure. CEMENT INTERNATIONAL (2017) No. 2, pp. 48–61.