Approach of a holistic integral strategy

Powerful precast technology and CO_2 management are not a contradiction

Prof. Dr. Jürgen Oecknick, PSA Zurich Area GmbH, Uster, Switzerland
Dipl.-Ing. Michael Erhardt, Hemmerlein Ingenieurbau GmbH, Bodenwöhr, Germany

Building materials markets are subject to constant change. The economic dynamics resulting in this context are due to the regionally prevailing political and social boundary conditions. For the cement industry, this means the need to adjust production capacities and the availability of specialist personnel to the cyclically changing demand for cement. The targeted manufacture of blended cements can be used in this process as an important instrument for the sensible control of the inevitable over- and under capacities of the market. Varying cement volumes on the basis of relatively constant clinker quantities – for the cement plants this not only results in effective "buffer scenarios", but the targeted production adjustments can also lead to "win-win" situations through the development of additional customer benefits. However, the sustainable implementation of ecological objectives is particularly important, and the blended cements produced will also create effects of high social significance by essentially reducing the CO_2-footprint.

Segmentation of the market as a planning tool for sustainable construction

The process-related know-how for the production of cements, modified with mineral additives like limestone, slag and pozzolana, has been state-of-the-art for decades. Despite this, there are still regional differences in the implementation of these technologies worldwide. In Germany, a clinker factor (ratio of clinker plus gypsum to addition of other main or minor mineral constituents) between 0.80 and 0.83 has proven itself for several years. While the clinker factor in China is currently still much lower at 0.65, clinker consumption in contrast in Russia (clinker factor = 0.9) can be classified as extraordinarily high, although the industry does already have a long tradition in producing and usage of slag cements. Even the installation of state-of-the-art plant technology has not yet brought a breakthrough towards sustainability in this market. The reasons for this stagnation can be found in the fact that the implementation of a holistic integrated strategy for the sustainable production and application of blended cements [1] (Table 1) has not started yet. So, obsolete standards can slow down the introduction of ecologically oriented cements. The same applies, for example, if the quality of the available aggregates is insufficient. The resulting deficits can only be compensated by increased proportions of clinker in the final mixture. In its integral component "Market", the integral strategy deals, among other things, with the price policy of cement producers, because ecologically oriented products only become mass-produced products if the sales price customary

Table 1: Holistic integral strategy

MARKET	RAW MATERIAL CEMENT	BINDING AGENT PRODUCTION	RAW MATERIAL FINAL PRODUCT	TECHNOLOGY PROCESSORS
• Segmentation in application • Bag/bulk ratio • State-of-the-art standards • Pricing policy	• Availability of mineral additives in: a) Quantity b) Transport proximity c) Grindability d) Material constancy e) Reactivity	• Clinker reactivity Mineral components: a) Filler effect b) Reactivity c) Quantity proportion d) Particle size distribution • Grinding, blending or combination	• State-of-the-art raw materials: a) Cement b) Special binder c) Aggregate d) Chem. admixtures e) Mineral additive	• State-of-the-art processing industry: a) Ready-mixed concrete b) Precast concrete elements c) Precast concrete products d) Dry mortar e) Civil engineering and special construction f) Bag cement user

Prof. Dr. Jürgen Oecknick – 40 years of professional practice in the national and international building materials industry and as a university lecturer on the subject of building materials process technology & marketing; experience in the manufacture and distribution of cement, ready-mix concrete and concrete products; he has worked for Schwenk, Dornburger Zement, Holcim and others; special knowledge of the design and sales of construction cement, special binders, white and oil well cement. juergen.oecknick@psazurich.ch

Dipl.-Ing. Michael Erhardt - successfully completed a degree course in Civil Engineering at the University of Munich in 1999; after that he worked as a project manager in the field of architectural concrete, specialising in façades; since 2006 he has been Managing Partner Sales and Project Handling at Hemmerlein Ingenieurbau GmbH. michael.erhardt@hemmerlein.com

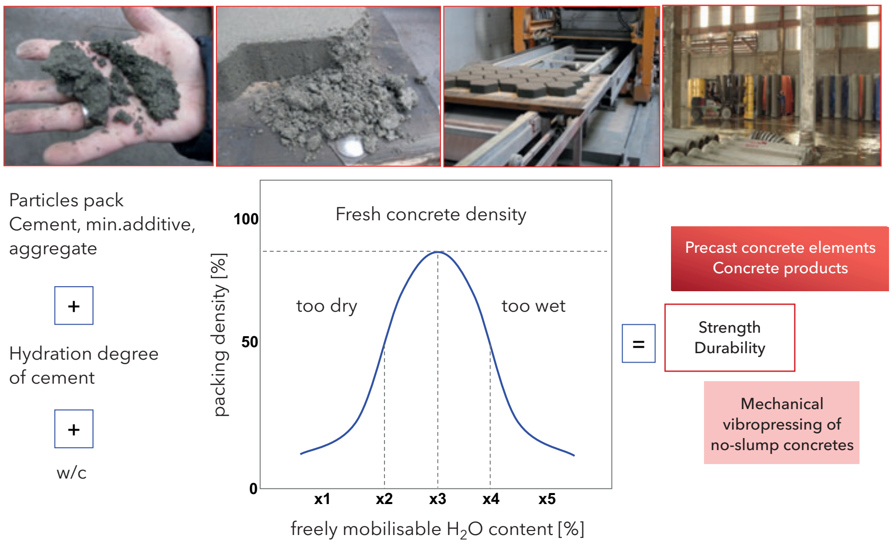

Fig. 1: Quality of no-slump concretes

in the market corresponds with their performance in industrial application. In order to create the conditions for this, every cement manufacturer must clearly segment the market as early as the product design phase, i.e. develop a clear idea of which segment, application field and product line the respective blended cement should be tailored to [2].

The prefabrication industry can derive its own procedural laws from this. As is well known, no-slump concretes are mechanically compacted in the precast sector. The desired parameters in terms of strength, deformation and durability are primarily a function of the packing density of the fresh mix and the hydration degree of the binder used (Fig. 1). The interaction of man, material and machine is the key to success. For the concrete technologist this means, in addition to assure all visual requirements, the fundamental task of generating as much "freely available" water as possible (not adsorbed by components of fresh concrete) despite low w/c values, which then guarantees the optimal compactability of the mixtures at the highest degree of cement hydration. From this point of view the clinker content usually contained in composite cements realizes the required target parameters of pressed concrete products and precast elements in full [3]. If this strategy is implemented nationwide, approx. 15 to 18 % of the cement market worldwide could be easily supplied with CO_2-reduced binding agents. There is no doubt that this influence on the total clinker factor cannot be compared with the possibilities offered by

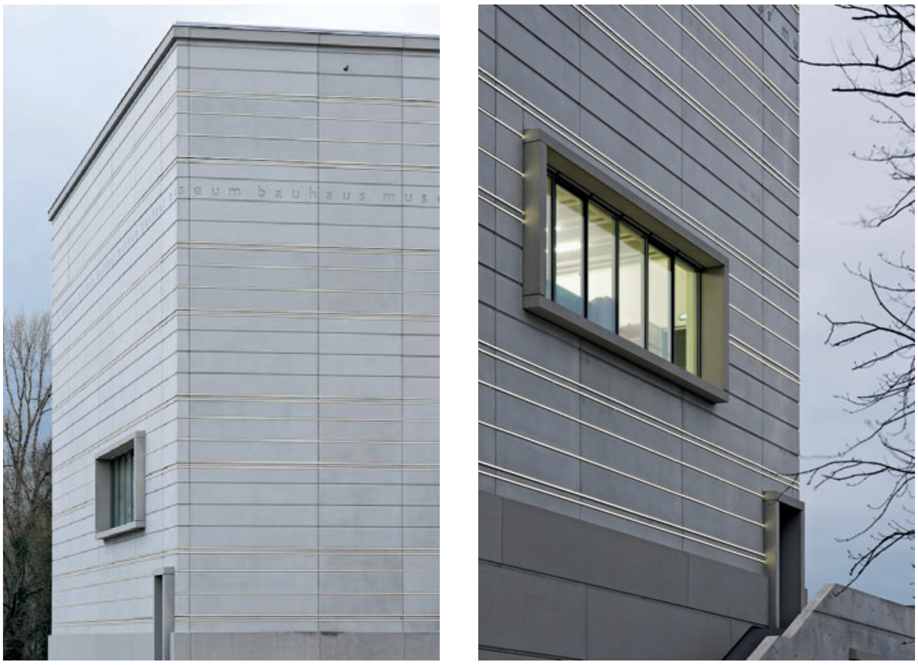

Fig. 2: Views of facade

ready-mixed concrete (approx. 60 % of the cement market). If, however, it were possible to tap the potential of CO_2-reduced cements also for the precast sector of flowable normal-hardening concretes (no heat treatment), then their share in the prefabrication industry could be increased from 75 to 80 % (pre-stressed concrete excluded). The task, however, is of a very complex nature, as the Portland cements usually used in this field of application due to their quick setting and hardening, are distinguished by high 12-hour strengths and a considerable release of hydration heat. This helps to ensure short cycle times and demanding precast surfaces on the basis of reasonable cement quantities per cubic meter of concrete. Blended cements cannot usually fully meet these criteria. However, in order to initiate ecological change on an industrial scale in this area of prefabrication as well, the precast element manufacturer must act in a complex manner and make targeted adjustments in the technological steps of work preparation, concrete formulation and manufacturing technology. With the fair-faced concrete façade of a cultural highlight in Weimar, Germany, Hemmerlein Ingenieurbau GmbH is now setting a first sign with social appeal in the direction of sustainable construction with precast elements made of flowable concrete.

The façade of the new Bauhaus Museum – a challenge in design, production and assembly

The unity of design and constructional sophistication has been guiding the façade builder hemmerlein from project to project for three generations - and it is concrete that demands everything from more than a hundred employees with its undreamt-of design possibilities, sharpening the senses forever new problem solutions. Today, the company, which is based in southern Germany and Switzerland, not only builds turnkey projects but also has an export volume of more than 30 percent in many metropolises on the European continent.

With the presented self-supporting, stacked façade of the new Bauhaus Museum to be built in Weimar, a very special project has been tackled since the start of production in December 2017. Approximately 400 reinforced concrete elements were to be provided as facades, wall girders, portals and entrance variants of the highest quality, i.e. the precast elements had to meet the highest requirements of the applicable standards and the latest fair-faced concrete guideline in terms of dimensional accuracy and flatness (Fig. 3), [4]. The focus here is on the sharp edges of the elements and the joint pattern as well as the colour consistency and uniform texture of the façade as a whole. Only in this way can the demand of Professor Hanada's design for a geometrically clear architecture be implemented in its entirety [5].

Fig. 3: Prefabricated façade elements

The material concept - "ecological yet efficient" - could be the motto of the Bauhaus concept of our time. However, effectiveness in the precast plant is usually defined by cycle times, which are determined by low w/c values, higher proportions of CEM I (OPC), or rapid hardening by support of heat treatment. With the material design for the façade of the new Bauhaus Museum, hemmerlein wanted to set new ecological standards - for itself also - on the basis of modern building material technology. Therefore, the first step was to select a white Portland limestone cement (CEM II/A-LL 52.5 N) with a production-related reduced CO_2 content of 15 % per ton of cement. The product from CRH, plant Rohoznik, not only forms the basis for a targeted control of the desired colour play on the concrete surface, the binder also provides the hardening kinetics of the fair-faced concrete required for the operating process despite the proportion of limestone as main constituent. The high clinker reactivity (according to CPTS 100 to 110 MPaJ/gmin) of the white composite cement from Slovakia forms the fundamental basis for this. This performance is technically justified by an optimisation of its phase contents and targeted adjustments in the degree of sulphatisation of the clinker. The ground final product thus stiffens quickly (first peak in the CPTS penetration process 10 to 20 min after water addition), delivers very short hardening times and the very intensive hydration heat development afterwards guarantees the required boost of the structure kinetics in the young concrete.

Hemmerlein achieved a further saving of 14 % CO_2 by reducing the cement content from 430 to 370 kg per cubic metre of concrete while at the same time complying with all requirements for the durability of the precast elements (C35/45, XC4, XF1). The principles for this were created by a series of concrete technology measures. The robustness of concrete, which is currently repeatedly "invoked" by experts, played an extremely subordinate role. Rather, the "stabilizing" fine materials should be avoided as far as possible in order to generate freely available water for a w/c value reduction while at the same time ensuring the highest possible compactability of the fresh concrete. This helps to ensure the planned cycle times and the required durability of the concrete to the full extent. The optimisation of the fine particles content begins with the elimination of the pigment. The RAL palette "white-grey" specified by the architect was achieved exclusively by mixing the white with a grey binder (also CEM II). The selective choice of the aggregates and a corresponding grading curve optimisation helped in the tapping of further quantities of freely available mixing water. As a result, the lower quantity of superplasticiser used (PCE) also produced a well-balanced material formulation with a reduced w/c ratio that guarantees the targeted yield point of the mix and at the same time delivers a fresh concrete with the lowest plastic viscosity.

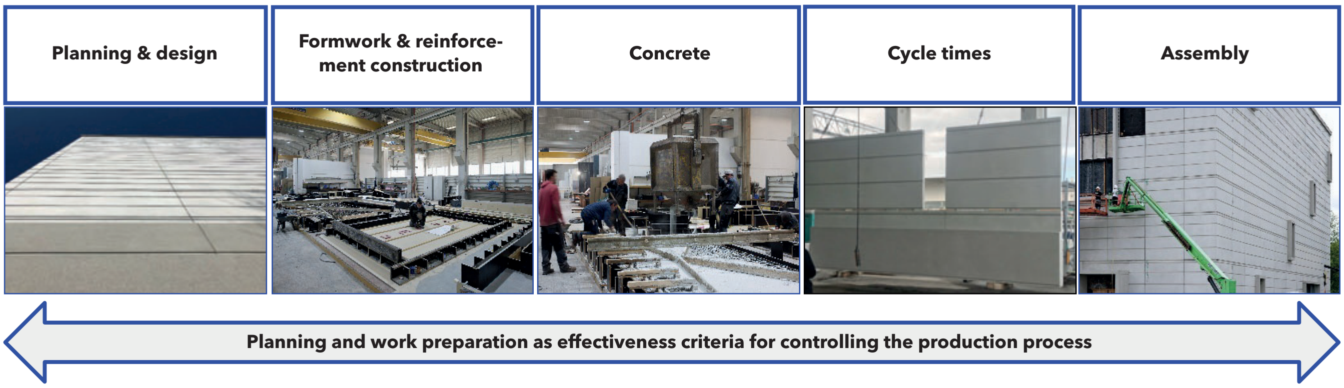

Fig. 4: Manufacturing process

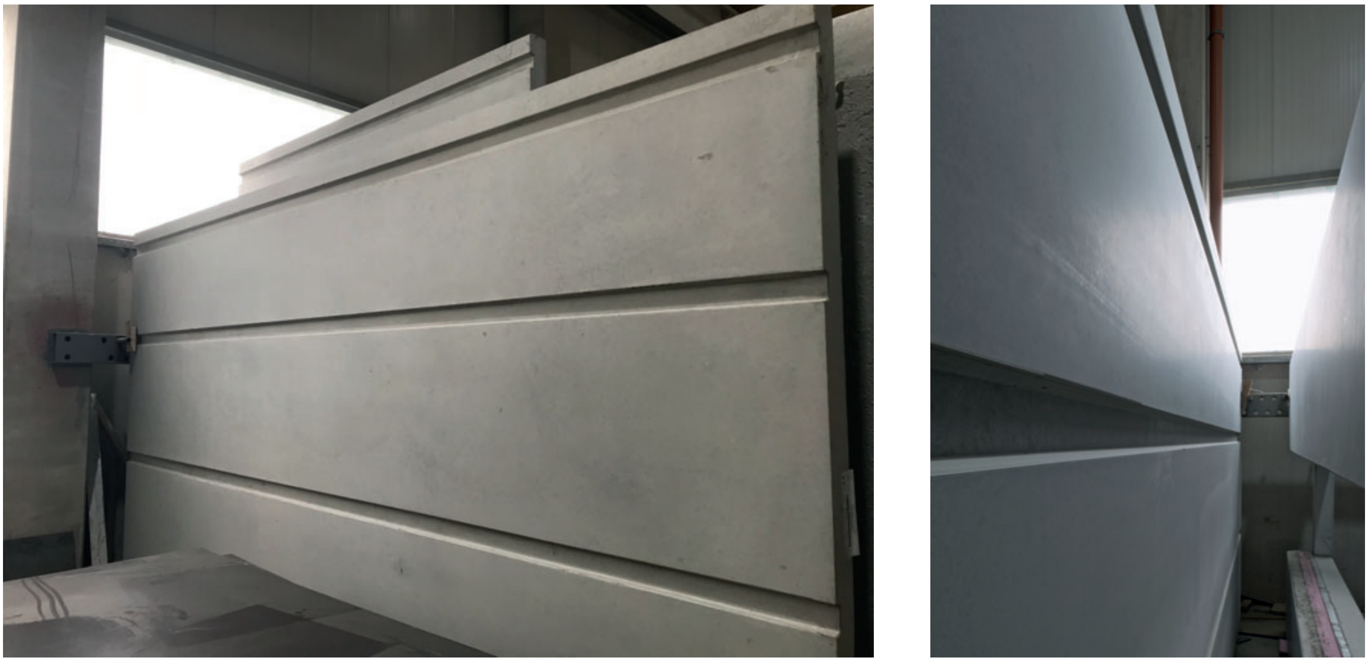

Fig. 5: Joint pattern of the elements

Production and assembly

The production process starts in every project with the model-based planning of all constructive details by the engineering office hemmerlein. The design of the reinforcement, joints and assembly statics then form the backbone of the work preparation. This in turn shapes the process chain in the precast plant (Fig. 4) with the following objectives:

- short cycle times despite use of blended cement and reduced binder content in concrete
- uniform reproduction of the agreed "mock-up" quality on the entire façade
- low tolerances in the component dimensions and exact joint formation with stable edges
- high durability of the façade in the planned life cycle of the building

The recipes developed for this purpose were precisely tailored to the selected formwork and compaction process in terms of water content and compactability. In addition, the white cement from Rohoznik should generate the corresponding kinetic potential in order to be able to accurately control the agreed RAL spectrum without any time delay in the de-moulding-, lifting- and transport processes and to produce one hundred percent formed component joints with high edge stability (Fig. 5).

The assessment of the first industrially manufactured elements by the clients in February 2018 ended with a satisfactory result for all partners involved. The discreet colour design of the concrete surface, which depicts an elegant alternation of light and shade on the façade elements through partially blasted surfaces, was already rated as particularly successful at this point.

Fig. 6: Intermediate storage and internal transport

In a final production step, the company had to shoulder the planned internal and construction site transport processes as well as the assembly of the precast reinforced concrete elements. The intermediate storage of the components plays a decisive part here (Fig. 6). As is well known, concrete carbonates continually and, influenced by the calcium ion concentration and the capillary transport of moisture, changes the hue of its surface, depending on the prevailing environmental

Fig. 7: Assembly of precast elements

conditions. The procedure of the intermediate storage therefore needs to be planned during the work preparation with the aim of purposefully controlling the colour changes of the architectural concrete of all the elements and thus to ensure a balanced façade design [6] in terms of appearance, construction and durability in the final phase of manufacturing too.

While the durability of the concrete is determined by the compliance with the specified exposure classes, the structural engineering of the components, coupled with the selected assembly construction, guarantees the projected resistance of the facade to late constraint, triggered by deformation through drying shrinkage or fluctuations in ambient temperature. Finally, bolted connections made of stainless steel ensure that the components are friction-locked to the shell construction of the building (Fig. 7).

The ceremonial opening of the museum took place as planned in April of this year exactly on the 100th anniversary of the "Bauhaus". In this context, it was also recalled that an additional glass envelope was planned for the building in the original design. Now it is exclusively architectural concrete - not only a highlight for the sustainably produced building material, but also an advertisement for the performance of the precast industry.

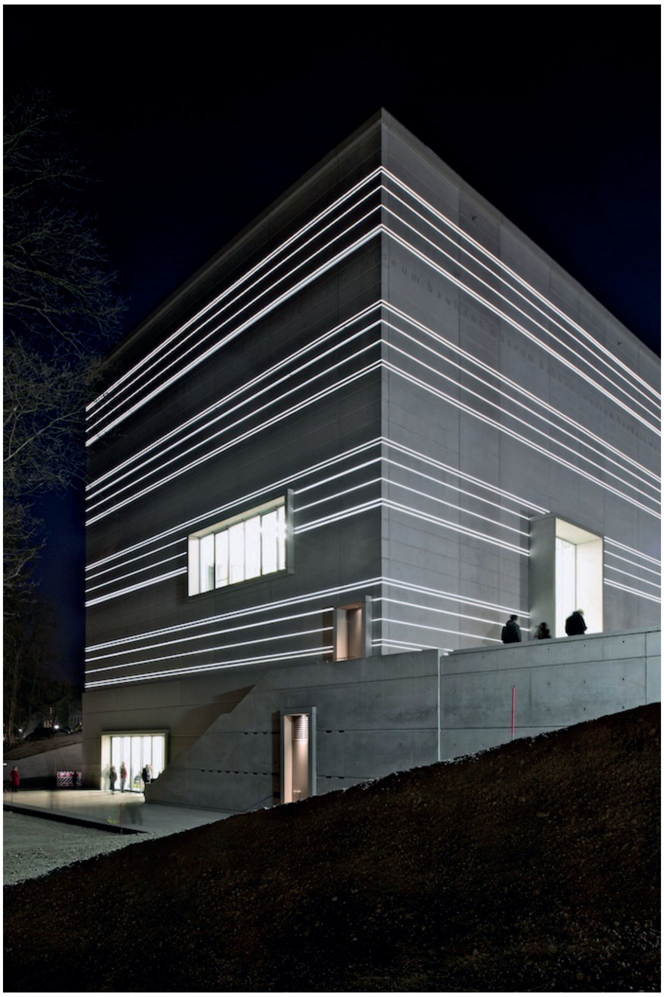

Fig. 8: Overall impression of the new Bauhaus Museum in Weimar

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FURTHER INFORMATION

PSA Zurich
PERFORMANCE SELLING ACADEMY

PSA Zurich Area GmbH
Freiestrasse 24a,
8610 Uster, Switzerland
juergen.oecknick@psazurich.ch
www.psazurich.ch

hemmerlein
Architekturbeton | Stahlbetonfertigteile | Ingenieurbüro

Hemmerlein Ingenieurbau GmbH
Industriestrasse 2
92439 Bodenwöhr, Germany
T +49 9434 94060
F +49 9434 940666
info@hemmerlein.com
www.hemmerlein-sichtbeton.de