ELEMENTS BULLETIN

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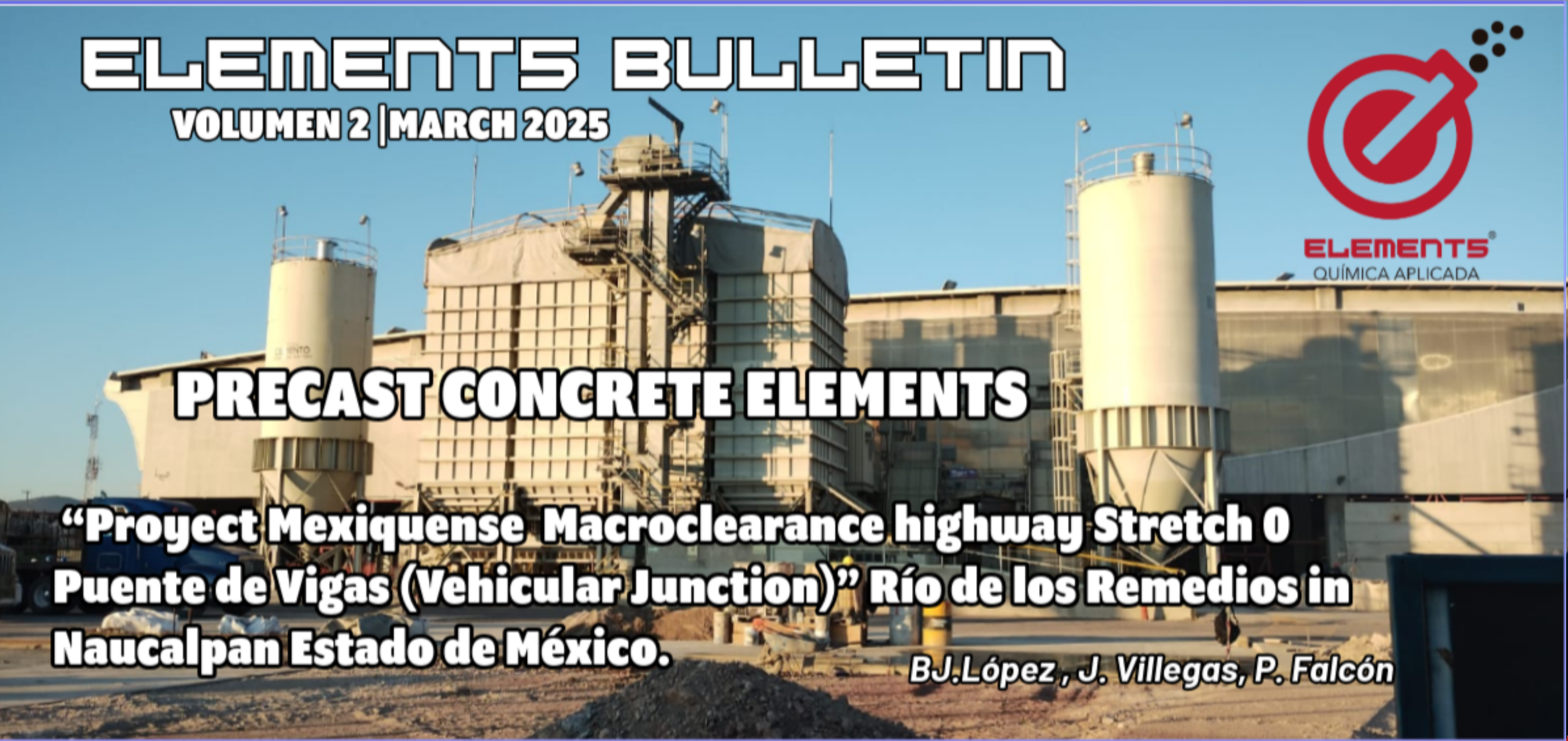
PRECAST CONCRETE ELEMENTS

"Proyect Mexiquense Macroclearance highway Stretch 0 Puente de Vigas (Vehicular Junction)" Río de los Remedios in Naucalpan Estado de México.

BJ.López , J. Villegas, P. Falcón



Background

The concrete precast elements have gained acceptance in construction, as the global prefab element market was 144.6 billion dollars in 2022 it is expected to reach 198.9 billion dollars in 2027. This implies a global growth of approx. 6.6%[1]. There are many benefits from the constructors point of view for the use of prefab elements, such as:

- Cost reductions, time and handwork decrease in job excecution.
- Construction improvement due to process standardization.
- Safety improvement in construction areas .
- Different to the in situ constructions, precast construction requires less resources, such as cement, steel, water, energy and handwoork. This generates less waste in the construction areas[2].

The precast concrete elements adopt a continuous production model in assembly lines, with multiple necessary rotations in one day to guarantee sufficient capacity. Time since concrete mix production until demolding determines the precast plant´s efficiency. Due to the above, depending on the type of elements and their characteristics, the development of a percentage of mechanical resistance of design at early ages is stipulated to perform element demolding[3]. To improve the mold rotation rate and the concrete production efficiency, constructors usually use two methods to accelerate cement hydration: i) the thermal curing and ii) chemical admixtures[4].

Thermal curing is a common practice during the production process. However, this method does not only use a lot of energy and has a high carbon footprint, but it also causes concrete strength loss in later ages[5]. For example, in some inquieries developed on this cost themes in prefab element construction plants in China, it was found that the integral energetic consumption obtained through the thermal curing construction process, approximately represents from 88.5 to 93.5% of the integral energy consumption of the entire production line of the unit product[6]. It was likewise discovered that thermal curing increases the proportion of large capillary pores within the concrete. This leads to exposure and deterioration of the element, with the consequence of a decrease in durability of the unit product in the long range[7]. For this reason, there is a focus in the exploration of technical solutions that may replace termal curing with adequate chemical admixtures. In academic research directed by Xie and coworkers it has been discovered that the sbstitution of the termal curing with chemical admixtures during precast of concrete columns conducts to a notable reduction of 72 kg de CO_2 per cubic meter of concrete produced (72 kg/m3)[8]. It was also discovered that using concrete admixture technology to prepare concrete for precast elements, CO_2 emissions decrease approximately 25%, in comparison with thermal curing[9].

Materials for concretes designed and mixed for precast elements.

As mentioned earlier, the development of initial strengths at early ages is fundamental for a prefab element plant. So an adequate selection of the required materials is vital in two ways. The first is from the point of view of compliance of the element´s technical specifications, such as mechanical strengths, structural specifications, durability etc. In the second there is and it is not less important, cost control. The characteristics of the materials used for mixing this type of concretes, which are, cement, aggregates, and admixtures.

Cement

In a general way the desired cements, due to their nature in strength development at early ages, it is that according to that described in the American standard ASTM C-15010 type III, or the equivalent in the Mexican standard NMXC-414[11], which corresponds to a cement CPC 40R or CPO 40 R, with high tricalcium silicate contents (C3S) and tricalcium aluminate (C3A), that have been identified to be the components responsible for strength development at early ages. However from a durability point of view it is not the most desirable and less if the elements will be in contact with sulfates.

This type of cements is not available in all parts of our country and due to international pressures to reduce the carbon footprint, manufacturers are in the need to modify cement formulations to reduce clinker content or cement morphology to have a lower impact on the environment. Let us remember that the cement industry is responsible for generating between 5 and 8% of the CO_2 emissions at a global level[12]. In some cases the use of supplementary cementitious materials such as pozzolans, fly ashes, blast furnace granulated slag, etc. can help to achieved these goals.

Cements with high limestone content and with calcined clays have also been introduced to the market as a way to achieve a decrease in CO_2 emissions. It is worthwhile to point out that this does not mean a decrease in cement quality, but it can have a delay effect in the development of mechanical strengths at early ages, which is contrary to what is desired in precast concret.

Aggregates

Scarcity of good quality aggregates in our country and in different parts of the world has become a challenge. Natural origin aggregates are less frequent, and crushed aggregates have become the most frequent. These show certain inconvenience, which can be morphology, clay content, slimes and crushing dust that can be included in aggregates. The presence of this particles increases water demand in mix designs to achieve the desired workability.

An interesting complementary method that is important to consider in aggregate selection is the methylene blue test ASTM C1777-2013. Besides traditional testing such as granulometry, density, absorption, bleach waste, morphology, etc. Tests related to water absorption that can be present when material with clay content is present in aggregates, which besides increasing water demand can delay strength development at early ages in concrete and in some cases even inhibit the dispersive effect of some superplatizicers.

Admixtures

To a large degree, the development of modern concretes is based in innovation of concrete admixtures. Even due to the presures derived from decreasing the carbon footprint in the cement industry, important changes are taking place in the process and in the cement, this has allowed that the admixture technology continue playing an important factor in concrete technology.

There is no doubt that superplasticizers are in the center of technology of chemical admixtures[14], first of all in their capacity to improve concrete workability, which can result in cost savings and secondly for their high volume. Superplasticizers base on polycarboxylates (PCEs), are a Japanese technology developed in 1981 by Dr. Tsuyoshi Hirata, as a response to materials problem´s for example low durability and other factors encountered by concretes at the time in Japan[15].

PCEs have gained a great position in the field of precast element concretes. New productors continuously enter the market with new products based on the existing technical knowledge or on a new advanced molecular design adapted to local requirements.
The principal characteristic of PCEs is a high dispersive power. This becomes concrete production with a very low water to binding materials ratio.

This has become an excellent strategy, in combination with the adequate materials to allow concretes to have strength development at early ages. In spite of its great benefits and through them, ultra-high concretes can be produced, or other type of concretes, PCEs, admixtures have some points that can decrease or deplete its performance.
For example, they´re extremely sensitive to clay impurities or silt in aggregates, which can significantly reduce it´s effectiveness in terms of fresh concrete workability and compressive strength of hardened concrete[16].

Diverse research showed that all clays and individual clay minerals are damaging, and the montmorillonite present is the most damaging material for PCEs[17]. In general superplasticizers can react with clays through two mechanisms:

1) Adsorption in its positively charged surfaces and
2) Through chemisorption (=intercalation)

between the principal surfaces (= aluminosilicate sheets) de montmorillonite (see Fig. 1). It is important to keep in mind that chemisorption is specific for montmorillonite clay and does not occur with most clays. The reason is that after the hydration the space between the aluminosilicate montmorillonite surfaces open due to the entry of water (=swelling), and then PCEs can also enter that space between layers or sheets[18]. Although some strategies recently exist within product formulations based on PCEs to overcome this problem. It has also been established that concrete formulated with low water to binding materials ratio exhibits a viscous consistency similar to honey, which is highly undesirable, however product technology exists that is capable of increasing flow speed or reduce stickiness, adherence, or viscosity of said concretes.

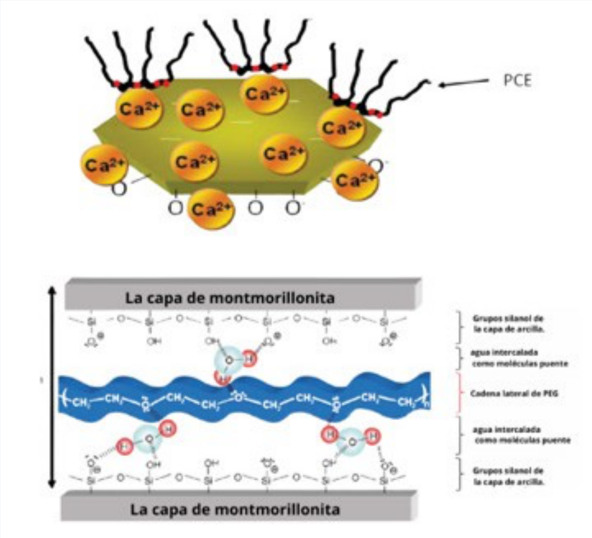


Fig.1. Interaction modes between anionic superplasticizers and clay particles: (above) superficial adsorption; and (below) chemical intertwining of PCE with ethoxylated lateral chains in the space between layers of montmorillonite clay reproduce from reference 18 [18].

Development in "high way: Macro libramiento Mexiquense stretch 0 Puente de Vigas (Vehicle junction)" Río de los Remedios in Naucalpan Estado de México

Project consists of the production 1890 beams AASHTO TYPE V. Materials used in the project are: type SR cement (sulfate resistant), crushed limestone aggregates, and superplasticizer admixture based PCE modified.

It is important to mention that a PCE technology tolerant to clays has been used; developed by our Element5 Quimica Aplicada research and development department. That product is e5 PCE A Clays SR, this besides helping the early age strength development and presenting clay resistance, it helps in the development of mechanical strengths at early ages with a consistency retention period of at least 2 hours.

With the use of PCEs available in the market, superplasticizer high demand problems are present due to the presence of clay materials and silt in aggregates, resulting in delays in initial strength development.

On the other hand and due to the nature of cement with CPC 40 RS characteristics for the specs mentioned in Table 1, the development of strength at early ages has been an important challenge as it is not the nature of SR cements.

Fig. 1. Plant for precast element production HOLPRE. Atitalaquia Estado de Hidalgo, México.

Specifications for Precast concrete elements

Most important specifications of the concrete are shown in Table 1, that follows. Likewise, the criteria established in NMX-C-530-ONNCCE-2018 were reviewed.

Concrete initial specifications	
28 day [kgf/cm^2] 80%f'c compressive strength	450
Mínimum strength development at 12 hours [kgf/cm^2]	360
Chloride ion rapid permeability at 56 days [Coulombs]	<2000
Maximum concrete temperature during production and placing [°C]	<32
Slump [cm]	24 ± 3.5
2 hours slump [cm]	24 ± 3.5
Fresh state included volumetric mass [kg/m^3]	2,300 - 2,450
Water to binding materials ratio not greater	0.45

Table 1. Concrete specifications.

Fig. 3. Placin of precast elements HOLPRE. Atitalaquia, Estado de Hidalgo, México.

Table 2 shows some results of the concretes mixed.

Concrete specifications		Valor
12 h [kgf/cm^2] 80%f'c mínimum compressive strength	360	409
Rapid chloride ion permeability at 56 días [Culombios]	<2000	663
Maximum concrete temperatura during mixing and placing [°C]	<32	28
slump [cm]	24 ± 3.5	26
2 h [cm] slump	24 ± 3.5	26
Volumetric mass in fresh state included [kg/m^3]	2,300 - 2,450	2375
Water to binding material ratio not higher than	0.45	0.29

Table 2. Parameters obtained in produced concrete.

Currently the 80% strength of f'c has been modified from 12 to 18 h, in compliance with the other specified parameters. A very careful quality control has been pursued for each one of the components, such as rock aggregates, cement and admixtures.

Fig. 2. Demolding and movement of precast elements.

Conclusions

The concrete mix design complies with the established technical specifications in table 1, which is required by the customer, and as required by the job´s mix design.
With a job coordinated between the technical departments from:

i) adequate materials selection
ii) the mix design
iii) the tests for spec compliance (pilote and industrial)
iv) the operations area in charge of the concrete mix preparation taking care of operating conditions.
v) placing of adequate concrete
vi) protection and demolding
vii) Transport and adequate placing of elements at the site.

Successful projects are warranties of a high spec technical demand.

From a technical point of view one of the largest challenges has been the achievement of mix properties with different banks of crushed aggregates. It has also been to achieve strength development at early ages with a cement with characteristics: SR and total elimination of thermal curing. The afore mentioned is possible due to concrete technology and the use of superplasticizers type PCE clay resistant.

Last but not the least important, mix design can complied as a or be classified as a very low permeability concrete due to the results obtained in ASTM C-1202 test, That extends the useful life of the prefab element, that, from a sustainability point of view has a positive impact.

References

1. Precast Concrete Market, Industry Size Forecast Report [Latest]. (s. f.). MarketsandMarkets. https://www.marketsandmarkets.com/Market-Reports/prefabricated-construction-market-125074015.html?gad_source=1&gclid=CjwKCAiAty8BhA_EiwAkyoa34Kx0Uvz7xrAW2GoG91aCcg7jOpdQNDh-hHT7fO-mRdmi8T0YxVxShoC8GUQAvD_BwE

2. Feng, X., Zhuo, C., & Yin, S. (2024). The application of C–S–H accelerators in the precast concrete industry: Early-age properties and CO2 footprint analysis. Journal of Cleaner Production, 435, 140558. https://doi.org/10.1016/j.jclepro.2024.140558.

EcuRed. (s. f.). Puente El Zacatal (México) - ECURed. https://www.ecured.cu/Puente_El_Zacatal_(M%C3%A9xico)

3. Alghazali, H. H., Aljazaeri, Z. R., & Myers, J.J. (2020). Effect of accelerated curing regimes on high volume fly ash mixtures in precast manufacturing plants. Cement And Concrete Research, 131, 105913. https://doi.org/10.1016/j.cemconres.2019.105913

4. Narmluk, M., & Nawa, T. (2011). Effect of fly ash on the kinetics of Portland cement hydration at different curing temperatures. Cement and Concrete Research, 41(6), 579-589. https://doi.org/10.1016/j.cemconres.2011.02.005

5. Türkel, S., & Alabas, V. (2005). The effect of excessive steam curing on Portland composite cement concrete. Cement and Concrete Research, 35(2), 405-411.

6. Wang, X., Xie, S., Wei, Z., & Wang, J. (2024). A Study on the Impact of China's Prefabricated Building Policy on the Carbon Reduction Benefits of China's Construction Industry Based on a Difference-in-Differences Method. Sustainability, 16(17), 7606. https://doi.org/10.3390/su16177606

7. Ba, M., Qian, C., Guo, X., & Han, X. (2010). Effects of steam curing on strength and porous structure of concrete with low water/binder ratio. Construction and Building Materials, 25(1), 123-128. https://doi.org/10.1016/j.conbuildmat.2010.06.049

8. Qi, Z., Liu, F., Deng, M., & Hu, J. (2021). Research on cleaner production potential of pipe pile industry based on material energy flow analysis. IOP Conference Series Earth and Environmental Science, 621(1), 012161. https://doi.org/10.1088/1755-1315/621/1/012161.

9. Kim, T. Y., Tae, S. H., & Yang, K. H. (2014). Life Cycle CO₂ Emission Assessment for Non-Steam Curing Precast Concrete. Advanced Materials Research, 1025-1026, 539-542. https://doi.org/10.4028/www.scientific.net/amr.1025-1026.

10. ASTM C150-07 Standard Specification for Portland Cement.

11. NMX-C-414-ONNCCE-2017 Industria de la Construcción - Cementantes Hidráulicos - Especificaciones y Métodos de Ensayo.

12. Sousa, V., & Bogas, J. A. (2021). Comparison of energy consumption and carbon emissions from clinker and recycled cement production. Journal of Cleaner Production, 306, 127277. https://doi.org/10.1016/j.jclepro.2021.127277

13. ASTM C1777-20 Standard Test Method for Rapid Determination of the Methylene Blue Value for Fine Aggregate or Mineral Filler Using a Colorimeter.

14. Ma, Y., Bai, J., Shi, C., Sha, S., & Zhou, B. (2021). Effect of PCEs with different structures on hydration and properties of cementitious materials with low water-to-binder ratio. Cement and Concrete Research, 142, 106343. https://doi.org/10.1016/j.cemconres.2020.106343

15. Lei, L., Hirata, T., & Plank, J. (2022). 40 years of PCE superplasticizers - History, current state-of-the-art and an outlook. Cement and Concrete Research, 157, 106826. https://doi.org/10.1016/j.cemconres.2022.106826

16. Nehdi, M. (2013). Clay in cement-based materials: Critical overview of state-of-the-art. Construction and Building 18. Li, Y., Duan, C., Meng, M., Zhang, J., Huang, H., Wang, H., Yan, M., Tang, X., & Huang, X. (2023). Effect of clay minerals on polycarboxylate superplasticizer and methods to improve the performance of concrete containing clay: a review. Journal of Materials Science, 58(39), 15294-15313. https://doi.org/10.1007/s10853-023-08989-0Materials, 51, 372-382. https://doi.org/10.1016/j.conbuildmat.2013.10.059
17. Lei, L., Palacios, M., Plank, J., & Jeknavorian, A. A. (2022). Interaction between polycarboxylate superplasticizers and non-calcined clays and calcined clays: A review. Cement and Concrete Research, 154, 106717. https://doi.org/10.1016/j.cemconres.2022.106717 A STM C1202-22e1 Standard Test Method for Electrical Indication of Concrete's Ability to Resist Chloride Ion Penetration.
18. Li, Y., Duan, C., Meng, M., Zhang, J., Huang, H., Wang, H., Yan, M., Tang, X., & Huang, X. (2023). Effect of clay minerals on polycarboxylate superplasticizer and methods to improve the performance of concrete containing clay: a review. Journal of Materials Science, 58(39), 15294-15313. https://doi.org/10.1007/s10853-023-08989-0
19. NMX-C-162-ONNCCE-2014 Industria de la Construcción - Concreto Hidráulico - Determinación de la Masa Unitaria, Cálculo del Rendimiento y Contenido de Aire del Concreto Fresco por el Método Gravimétrico.
20. NMX-C-157-ONNCCE-2006 Industria de la Construcción - Concreto - Determinación del Contenido de Aire del Concreto Fresco por el Método de Presión.

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