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HIGH-VOLUME LIMESTONE POWDER CONCRETE FOR STRUCTURAL APPLICATION

Summary: This paper presents the key results of a comprehensive experimental, numerical and analytical study of concrete with a high limestone powder content. The testing programme covered all aspects, from mix design, through mechanical properties and durability parameters, to the behaviour of real-scale RC beams under sustained loading over 1000 days, including the development of cracks, strains in the concrete and reinforcement, as well as concrete shrinkage and creep. Results showed that concretes with over 55% of cement replaced by limestone powder can be produced and successfully applied in RC structures, with properties similar to conventional concrete. Based on own and available literature data, it was established that existing prediction models for material properties, durability and beam deflection, which were developed for conventional concrete, can, with certain corrections, also be applied to concretes with high limestone powder content.

Keywords: RC beams, sustained load, mechanical properties, durability performance, life-cycle assessment

BETONI SA VELIKIM SADRŽAJEM KREČNJAČKOG BRAŠNA ZA KONSTRUKCIJSKU PRIMENU

Rezime: Rad prikazuje ključne rezultate obimnog eksperimentalnog, numeričkog i analitičkog istraživanja betona sa velikim sadržajem krečnjačkog brašna. Ispitivanja su obuhvatila sve aspekte od razvoja receptura, preko mehaničkih svojstava i parametara trajnosti, do ponašanja realnih AB greda pri dugotrajnom opterećenju tokom 1000 dana, uz praćenje razvoja prslina, dilatacija u betonu i armaturi, ali i skupljanja i tečenja betona. Rezultati su pokazali da se mogu napraviti i uspešno primeniti u AB konstrukcijama betoni kod kojih je i preko 55% cementa zamenjeno krecnjackim brasnom, sa svojstvima sličnim tradicionalnom betonu. Na osnovu sopstvenih i podataka iz dostupne literature, ustanovljeno je da se postojeći modeli za predikciju materijalnih svojstava, trajnosti i ugiba nosača koji su razvijeni za tradicionalne betone, mogu, uz određene korekcije, primeniti i na betone sa velikim sadržajem krečnjackog brašna.

Ključne reči: AB grede, dugotrajno opterećenje, mehanička svojstva, parametri trajnosti, procena životnog ciklusa

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1. INTRODUCTION

Current global cement production stands at approximately 4.1 billion tonnes per year [1,2], and together with concrete as its end product, remains one of the most widely produced materials in human history. Continued urbanisation and infrastructure development, particularly in emerging economies, are expected to sustain strong demand in the coming decades, although the precise long-term trajectory of production remains uncertain and depends strongly on the pace of decarbonisation across the sector [1].

This scale of production comes at a considerable environmental cost, primarily due to the clinkerisation process, which involves the calcination of limestone and the combustion of fuel at high temperatures. This inherently carbon-intensive process is responsible for a substantial share of global anthropogenic CO_2 emissions, commonly reported at around 7–8% [1]. A significant part of these emissions, approximately 60%, originates from the chemical decomposition of limestone during calcination itself, a process-related emission that cannot be avoided by fuel-side measures alone. The remaining share is associated with the combustion of fuel needed to reach the high kiln temperatures required for clinker formation [3].

Reflecting this dual origin, current decarbonisation strategies for the sector combine measures addressing both emission sources: a shift away from fossil fuels, improved energy efficiency, increased substitution of clinker by supplementary materials, the development of novel low-carbon binders, and the deployment of carbon capture and storage.

In this context, the Global Cement and Concrete Association (GCCA), through its 2050 Roadmap to Net Zero Concrete [3], has identified reduction of the clinker factor of cement as one of the most significant near-term levers. The plan is to reduce the clinker content in cement to approximately the same level as mineral additives by 2050, effectively equalizing the proportion of clinker and supplementary constituents in the cement.

Limestone powder (LP) has emerged as a particularly attractive material in this context. Unlike fly ash or slag whose availability is tied to, and expected to decline alongside, coal-fired power generation and traditional steelmaking, respectively, limestone is abundant, geographically widespread, and available in practically unlimited quantities relative to current and foreseeable demand (Figure 1) [4]. It can also be produced with considerably lower embodied energy than clinker, since, unlike clinker production, it does not require calcination at comparably high temperatures.

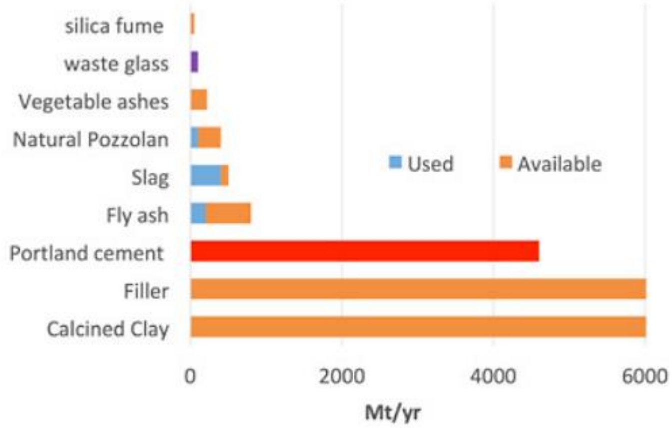

Figure 1: Estimated availability and current use of selected alternative cementitious materials worldwide [4]

Its use as a main constituent of cement is already recognised in standards such as EN 197-1 [5], which permits limestone contents of up to 21–35% in common cement types (e.g., CEM II/B-

LL) and higher proportions in certain ternary blended cements. In practice, however, the limestone content actually used in cement production remains, on average about 7% [4], well below these permitted maximum values, leaving considerable unused potential for further clinker reduction.

Beyond these established practices and codified limits, a growing body of research has explored so-called high-volume limestone powder concrete (HVLPC), in which limestone powder replaces a considerably larger share of the clinker, beyond 35%. Moreover, in some studies limestone powder exceeding 50–70% of the total powder content, as a means of further reducing the carbon intensity of concrete, in line with the ambition to reduce carbon intensity across the entire cement and concrete value chain. If such ambitious sector-wide targets are achieved, Europe is expected to reach carbon neutrality, i.e. a balance between emitted and captured CO_2 within the next 25 years, in line with the European Green Deal's 2050 net-zero objective [6].

2. LITERATURE REVIEW AND RESEARCH GAPS

At the material level, the influence of LP on concrete properties is generally attributed to two combined effects. A physical filler effect accelerates early hydration and refines the pore structure [7]. A dilution effect, caused by the reduced clinker content, lowers the amount of hydration products and, beyond a certain replacement level, reduces both mechanical performance and durability [7]. Existing critical reviews indicate that HVLPC mixtures can be designed with mechanical and rheological performance comparable to reference concrete, but this generally requires a higher superplasticizer dosage [8,9].

Compressive strength, as the basic property of concrete, has been analysed in a large number of studies [10–12]. However, the influence of LP on this property is still not sufficiently understood: no simple expressions are currently available to describe the effect of the main mixture parameters on strength, and although the fineness of LP is considered to have a positive effect, this relationship has not yet been sufficiently clarified. Moreover, other mechanical properties are generally assumed to follow this trend, though it remains unclear whether they follow the same relationships established for conventional concrete, or whether the corresponding code expressions for their prediction can be applied to HVLPC without modification.

When it comes to durability, existing research indicates that performance tends to remain inferior to that of reference concrete, while reliable prediction models for this class of concrete are still lacking [8,12].

Real-scale structural elements have received very limited attention. In particular, their behaviour under long-term sustained loading, where creep and shrinkage govern serviceability limit states, remains largely unexplored. The reduced cement paste content may affect these time-dependent phenomena in ways that are not adequately captured by models developed for conventional concrete [13]. Consequently, the applicability of existing prediction models to HVLPC structural elements remains uncertain.

Finally, the life-cycle environmental and economic performance of HVLPC has received limited attention, despite being an important aspect of assessing its overall sustainability.

The doctoral research summarised in this paper was carried out at the Faculty of Civil Engineering, University of Belgrade, and presented in the dissertation “Structural Concrete with Reduced Cement and High Limestone Powder Content” [14]. The research was designed to progressively address the main research needs from the existing literature, comprising an extensive, multi-stage experimental campaign that progressed from material- and mixture-level characterisation through durability assessment to full-scale, long-term testing of reinforced concrete beams.

Experimental results were combined with data from the literature into a unified database to assess the applicability of existing prediction models and, where necessary, support their calibration or modification for HVLPC. The research was further complemented by life-cycle and cost assessments, providing an integrated evaluation of the technical, structural, and environmental performance of HVLPC.

3. EXPERIMENTAL PROGRAMME

Owing to its scope, the experimental programme was divided into three phases:

- Testing of the compressive strength and workability of HVLPC and reference cement concretes at different ages,
- Testing of physical-mechanical properties and durability parameters on selected mixtures from the first phase,
- Testing of the behaviour of reinforced concrete beams under sustained loading over 1000 days.

A separated, three-fraction river aggregate with a maximum nominal size of 16 mm and a density of about 2600-2650 kg/m^3 was used. Ordinary Portland cement (CEM I), with a density of about 3100 kg/m^3, and a polycarboxylate-based superplasticizer, with a density of about 1075 kg/m^3, were also used. In addition, four limestone powders of the same origin were used. Two of these were finer than the cement (K1, K2), one was of similar fineness to the cement (K3), and one was considerably coarser (K4). Their density was about 2600-2700 kg/m^3. The particle size distribution of the limestone powders and the cement is shown in Figure 2. Mixing was carried out in a vertical rotary mixer and lasted on average about 5 minutes.

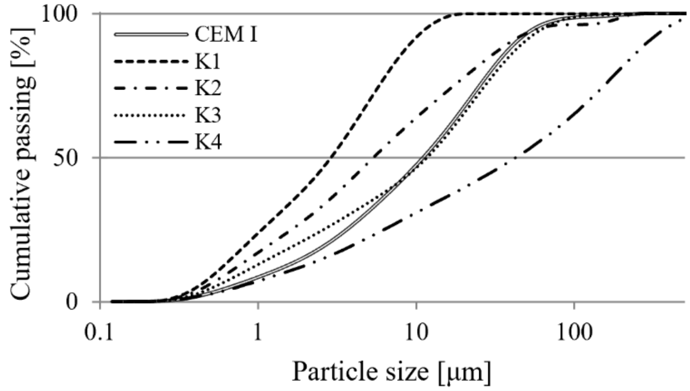

Figure 2: Particle size distribution of limestone powder and cement

3.1. FIRST PHASE: WORKABILITY AND STRENGTH

Since compressive strength is the most important parameter of concrete, and given the gaps identified in the literature review, the entire focus of the first phase was devoted to this property. A very extensive investigation of all relevant parameters influencing strength was carried out. Once the mix designs were defined, the influence of the cement replacement level, that is, the amount and particle size distribution of LP, the water to cement (w/c) ratio, and the age of the concrete, was analysed in detail.

Table 1: Review of designed mixtures in the first phase with the most important parameters

Concrete Mix	Cement [kg]	Limestone [kg]	Lim. type	w/c
Referent	330	0	/	0.45 – 0.7
HVLPC 30%	230	100; 150; 200	K1 – K4	0.45 – 0.7
HVLPC 45%	180	150; 200; 250	K1 – K4	0.55 – 0.7
HVLPC 55%	150	230; 280	K1 – K4	0.65 – 0.8
HVLPC 65%	120	260; 310	K1 – K4	0.80 – 1.0

Across this experimental campaign, and across all three phases, approximately 220 concrete mixtures were designed, including trial batches, comprising both reference cement concretes and HVLPC. An indicative overview of the mix compositions is given in Table 1. Simple mass replacement of cement did not always provide the desired concrete properties, and the water content often also had to be reduced, resulting in a lower volume of cement paste. In some cases, therefore, cement was replaced on a volumetric rather than mass basis. In this approach, the reduction in paste volume was compensated by adding a larger mass of LP than the amount of cement replaced.

Characteristic slump shapes observed during the workability tests are shown in Figure 3. In general, LP mixtures exhibited poorer workability than the reference mixtures, and were often stiff, with zero or even shear slump (Figure 3c). Nevertheless, the tests showed that, through appropriate selection of the component materials and their proportions, together with a suitable superplasticizer, mixtures with very good workability could still be obtained (Figure 3a, b), even with more than 50% of the cement replaced. The use of finer LP is recommended to achieve better workability.

Figure 3: Workability of fresh concrete, thrue slump (a), flow (b), shear slump (c)

Part of the compressive strength results is shown in Figure 4, while the remaining results are presented in detail in the doctoral dissertation [14]. Unlike workability, the influence of LP on compressive strength proved to be positive. At the same w/c ratio, HVLPC concretes exhibited significantly higher strength than the corresponding reference concretes in all cases, with the difference exceeding 50% in some instances. Finer limestone powders proved to be a better choice than coarser ones, which can be attributed to improved particle packing density within the mixture. A similar effect was observed with an increase in the powder content of the mixture. The introduction of an LP efficiency factor made it possible to incorporate LP content as a parameter in existing compressive strength prediction models, resulting in relatively good predictions.

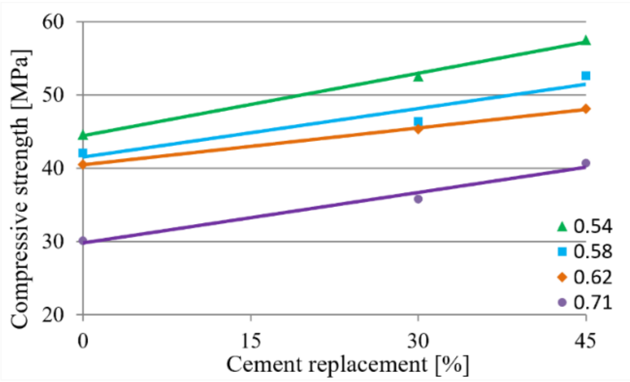

Figure 4: Compressive strength regarding to w/c ratios and percentage of cement replacement [15]

The time-dependent development of concrete strength is well described by a logarithmic trend and is primarily governed by the type of cement used [16]. The influence of other parameters is generally of secondary importance, except at very early ages, when their effects become more pronounced.

3.2. SECOND PHASE: MECHANICAL PROPERTIES AND DURABILITY

In the second phase, the remaining physical-mechanical properties were tested on ten mixtures selected from the first phase. These included splitting tensile strength, flexural tensile strength, modulus of elasticity, water penetration under pressure, freeze-thaw attack, chloride penetration, natural and accelerated carbonation. Concretes of common strength classes (C25/30 and C30/37) were selected for this purpose, in which 0%, 30%, 45% and 55% of the cement was replaced by LP, and three LP powders of different particle size distributions were used in this phase. The coarsest (K4) LP was excluded from further analysis due to insufficiently favourable characteristics.

The mechanical properties of HVLPC were similar to, or somewhat better than, those of the reference concretes. This can be explained by their similar compressive strengths. However, in some cases, HVLPC exhibited significantly better mechanical properties than the reference concretes, most notably in flexural tensile strength [17].

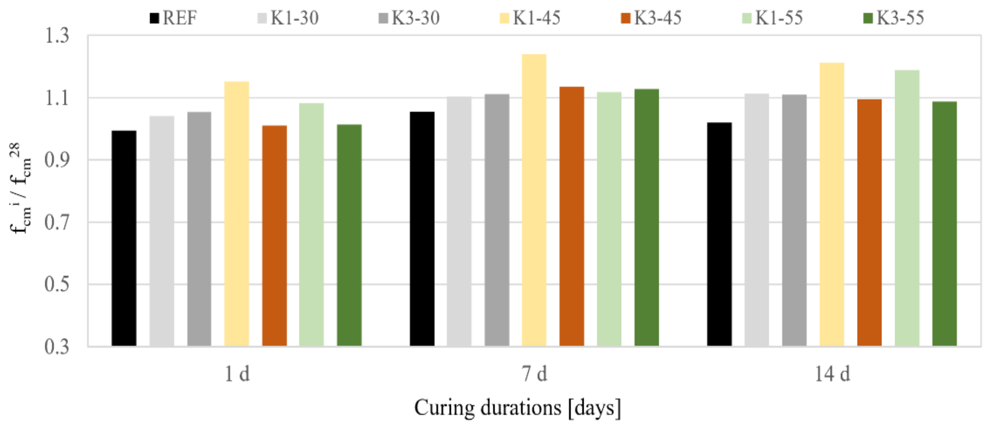

Figure 5: The effect of curing duration on the compressive strength

Unexpectedly, prolonged curing did not significantly affect the final compressive strength, Figure 5. More precisely, curing in water up to the age of 7 days had a positive effect on the strength achieved: the longer the concrete was cured in water, the higher its compressive strength. In contrast, extending curing in water to 28 days did not provide the expected benefit. Compared with the other curing regimes, these strengths were generally lower. These findings are not consistent with results reported in the literature for LP concrete [18], but agree with results obtained for other types of concrete [19–21]. A possible explanation is higher pore water pressure caused by the presence of water, so the beneficial effect of prolonged curing could be expected to appear only after the specimens have fully dried.

Unlike the other mechanical properties, prolonged curing had the greatest effect on flexural tensile strength. The results clearly indicate that flexural strength increases with increasing curing duration in water, Figure 6.

More detailed analyses of the tested mechanical properties, together with the modified prediction models developed for HVLPC, are provided in the doctoral dissertation [14].

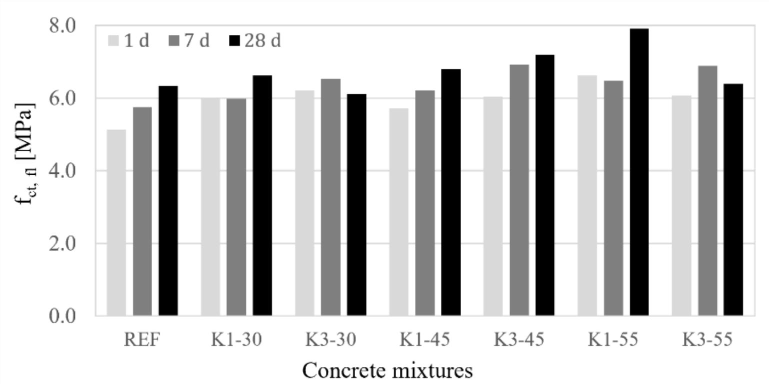

Figure 6: The effect of curing duration on the flexural strength

In terms of durability, the water penetration under pressure test showed a positive effect of LP. All HVLPC mixtures recorded significantly lower penetration depths than the reference concretes. This is also where the positive effect of prolonged curing is most clearly observed: in some cases, specimens cured in water for 28 days had a 2-3 times lower water penetration depth than those cured for 7 or 1 day.

Regarding carbonation, HVLPC exhibited somewhat poorer natural carbonation performance than the reference concretes. This was confirmed when testing the existing fib model for predicting carbonation resistance: the fib relationship between the natural and accelerated inverse carbonation resistances was found not to be valid for HVLPC [22,23]. Depending on the LP content, modifications to this relationship were proposed, separately for mixtures containing 21–35% and 36–70% LP in the powder phase [22]. Relationships between the natural inverse carbonation resistance and the mean compressive strength of concrete were also established for these two groups. Using the proposed prediction models, a full probabilistic service life analysis was performed [24], showing the need for increased cover thickness to ensure the service life required by the codes. In the case of accelerated tests, the differences were more pronounced, Figure 7. The effect of prolonged curing was also very positive in this case [25].

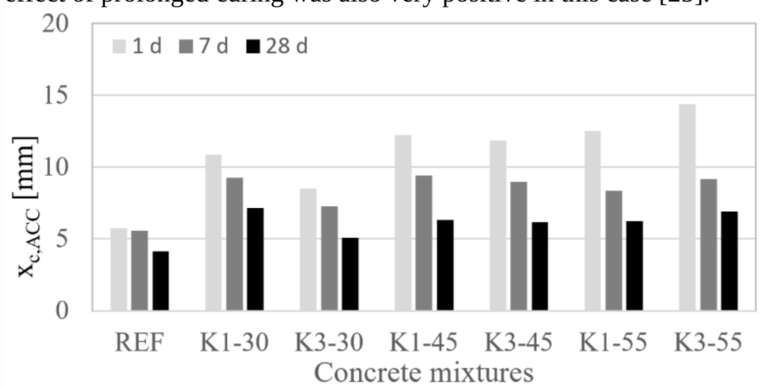

Figure 7: The effect of curing duration on the carbonation depths under accelerated conditions

The chloride penetration test showed considerably poorer behaviour of HVLPC concretes, without a significant effect of prolonged curing. This can be explained by the lower content of aluminate phase and dilution of the cement paste [7,9].

The worst results were recorded in the freeze-thaw and de-icing salt resistance tests, where, in general, all tested concretes performed rather poorly, in some cases accompanied by significant specimen degradation, Figure 8. A more detailed presentation of these results is available in [17,22–25].

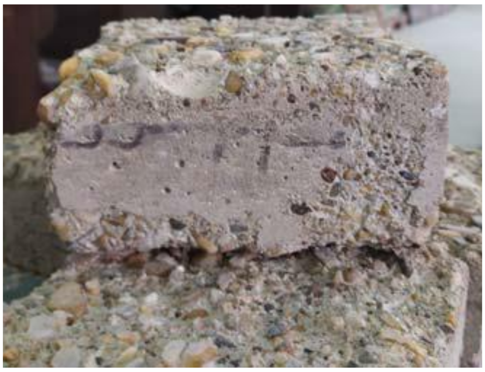

Figure 8: Appearance of damaged samples after freeze-thaw test

3.3. THIRD PHASE: RC BEAMS

In the third phase, the focus shifted to the behaviour of reinforced concrete beams under sustained loading, over a period of 1000 days. Under laboratory-controlled thermo-hygrometric conditions, in addition to long-term properties such as concrete shrinkage and creep, cracks, section curvatures and deflections were also analysed. A total of six beams were tested: two reference beams, and four beams in which 45% of the cement was replaced by LP of different particle size distributions. The beams had a rectangular cross-section of 16×20 cm, a total length of 350 cm, and a clear span of 320 cm. They were loaded by concentrated forces at the third-points of the span. The test setup is shown in Figure 9.

Figure 9: Experimental setup: four-point bending test

The tests showed positive effects of LP on concrete shrinkage and creep, as well as on deflection and crack widths. The recorded initial and final deformed states of the beams, with the corresponding deflection values, are shown in Figure 10. The structural behaviour of the HVLPC beams was clearly better, with markedly smaller deflections. The initial deflection values of the HVLPC beams were about 50% lower, while the final values were up to 75% lower than those of the reference beams.

In addition to the lower absolute values, HVLPC beams also showed a lower rate of increase in deflection, as well as in the other measured quantities, over time. The time development of deflection is shown in Figure 11. All time-dependent quantities can be very well approximated mathematically by logarithmic functions.

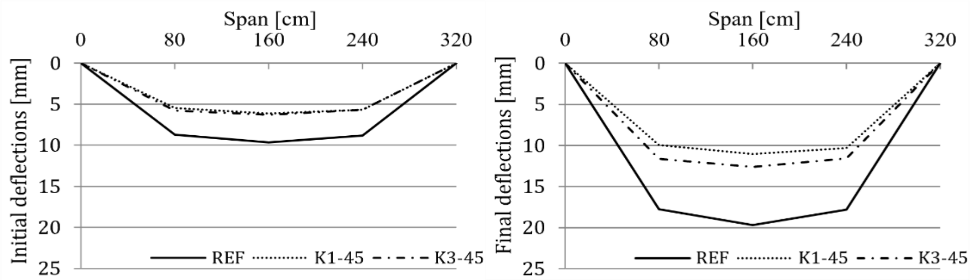

Figure 10: Deformed beams configuration: initial and final

Subsequent analyses showed that the models proposed by the new Eurocode 2 [26] for conventional concrete cannot be reliably used for HVLPC. This problem can be addressed by calibrating the models, after which very good agreement can be achieved, with differences of less than 10%. If these, together with all other experimentally determined quantities, are introduced into the deflection prediction model proposed by the new Eurocode 2, fairly good predictions are obtained, in agreement with the measured values. A more detailed account of the behaviour of the RC beams can be found in [16].

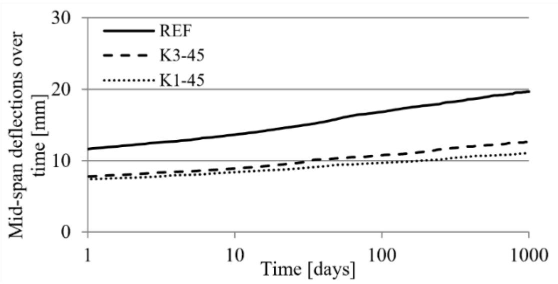

Figure 11: Mid-span deflections over time

4. ENVIRONMENTAL IMPACT AND COST ASSESSMENT

This chapter provides a holistic assessment of the suitability of HVLPC for structural applications, combining environmental, economic and structural performance using the ECO_2 method [27]. The application of these concretes was analysed through two types of selected structural elements, of different stress states and geometry: slabs and columns.

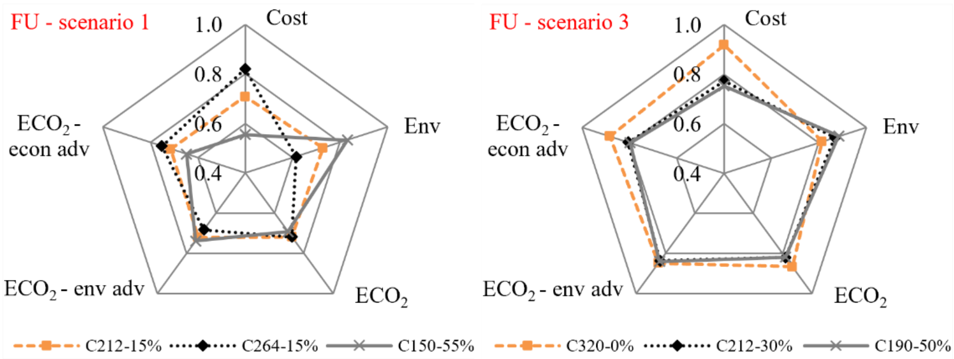

Figure 12: ECO_2 score for the best three concrete

For the purposes of this study, a Cradle-to-Gate scope was adopted. This includes all processes and emissions associated with the production of the individual constituents and their transport to the concrete production plant. The functional unit was defined as the volume of concrete per 1 m^2 of RC slab area (Scenario 1), and per 1 m' of RC column height in a four-storey building (Scenario 3), required to ensure equal strength, service life and serviceability.

Environmental, economic, and ECO_2 scores for the three best-performing concrete mixtures are shown in Figure 12. In Scenario 1, all three top-ranked mixtures contained LP, and given the small differences in the final score, all can be regarded as optimal solutions. In Scenario 3, two of the top three positions were occupied by HVLPC, and one by the reference concrete. As in the previous case, given the small differences, these can also be regarded as optimal solutions. A more detailed account of the LCA, environmental and cost indicators is available in [28].

5. CONCLUSIONS

This paper has presented the results of a comprehensive investigation of HVLPC, combined with a database formed using own and literature data. Based on these results, the following conclusions can be drawn:

- In the fresh state, HVLPC mixtures generally exhibit poorer workability than the corresponding reference concretes, since limestone powder acts as a negative factor in this respect. However, with an appropriate selection of the component materials and their proportions, together with the addition of a superplasticizer, workability can be significantly improved.

- Limestone powder had a positive effect on the compressive strength of HVLPC. At the same w/c ratio, this resulted in a strength increase, attributed to an improved particle packing effect. This difference becomes more pronounced with increasing limestone powder content. Regarding particle size distribution, finer limestone powder should be preferred. An efficiency factor was introduced for LP, enabling its content to be used as a parameter in existing strength prediction models, with relatively good results.

- HVLPC can achieve mechanical properties similar to, or even better than, those of the reference concretes. Prolonged curing generally contributes to a further improvement of all mechanical properties, although this effect is more pronounced for some properties than for others. These properties can be successfully predicted using existing models, with the proposed modifications for HVLPC.

- The durability of HVLPC is generally compromised by the dilution effect of the cement paste. Examples of a positive effect of limestone powder can also be found for some durability properties, such as water penetration resistance. The carbonation resistance of these concretes gradually decreases compared with the reference concretes, but it can be well predicted using the proposed models. The poorest performance was observed for chloride penetration and freeze-thaw resistance.

- HVLPC concretes showed better structural performance, accompanied by reduced shrinkage and creep compared with the reference concretes, and beams made of these concretes exhibited significantly smaller deflections and narrower cracks. Through calibration of existing prediction models, these effects can be successfully predicted with satisfactory accuracy and accounted for in design.

- A fair comparison of the environmental and economic indicators of concretes with different performance levels was ensured by appropriately defining the functional unit, which, in addition to load-bearing capacity, also included durability. Concretes containing limestone powder showed a clear and significant environmental advantage in all cases, while the economic criteria were mixed. This did not affect the results obtained for RC slabs, for which the overall score was clearly in favour of these concretes. However, it did affect the results for columns, where the final score was split, meaning that both the reference and the HVLPC concretes performed equally well in this case.

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REFERENCES

[1] Habert, G., Miller, S. A., Provis, J. L., Favier, A., Horvath, A. & Scrivener, K. L., Environmental impacts and decarbonization strategies in the cement and concrete industries, Nature Reviews Earth & Environment volume, Vol. 1, 2020, 559–573. https://doi.org/https://doi.org/10.1038/s43017-020-0093-3

[2] USGS, Mineral Commodity Summaries 2025, U.S. Geological Survey, 2025, 212. https://doi.org/10.3133/mcs2025

[3] GCCA, CONCRETE FUTURE: The GCCA 2050 Cement and Concrete Industry Roadmap for Net Zero Concrete, Global Cement and Concrete Association, 2021, London. https://gccassociation.org/concretefuture/wp-content/uploads/2021/10/GCCA-Concrete-Future-Roadmap.pdf

[4] Working group UNEP-SBCI, Eco-efficient cements: Potential economically viable solutions for a low-CO2 cement-based materials industry, United Nations Environment Program - Sustainable Building and Climate Initiative, 2015, 1–64. https://wedocs.unep.org/bitstream/handle/20.500.11822/25281/eco_efficient_cements.pdf

[5] EN 197-1, Cement - Part 1: Composition, specifications and conformity criteria for common cements, European committee for standardization, Brussels, 2013.

[6] European Commission, The European Green Deal, 2019, Brussels.

[7] John, V. M., Damineli, B. L., Quattrone, M. & Pileggi, R. G., Fillers in cementitious materials — Experience, recent advances and future potential, Cement and Concrete Research, 114, 2018, 65–78. https://doi.org/10.1016/j.cemconres.2017.09.013

[8] Marinković, M., Radović, A. & Carević, V., Carbonation of limestone powder concrete: State-of-the-art overview, Building Materials and Structures, 66, 2023, 127–139. https://doi.org/10.5937/GRMK2300005M

[9] Wang, D., Shi, C., Farzadnia, N., Shi, Z. & Jia, H., A review on effects of limestone powder on the properties of concrete, Construction and Building Materials, 192, 2018, 153–166. https://doi.org/10.1016/j.conbuildmat.2018.10.119

[10] Tešić, K., Marinković, S. & Savić, A., Influence of cement replacement with limestone filler on the properties of concrete, Building Materials and Structures, 64, 2021, 165–170. https://doi.org/10.5937/grmk2103165t

[11] Proske, T., Hainer, S., Rezvani, M. & Graubner, C. A., Eco-friendly concretes with reduced water and cement contents - Mix design principles and laboratory tests Cement and Concrete Research, 51, 2013, 38–46. https://doi.org/10.1016/j.cemconres.2013.04.011

[12] Lollini, F., Redaelli, E. & Bertolini, L., Effects of portland cement replacement with limestone on the properties of hardened concrete, Cement and Concrete Composites, 46, 2014, 32–40. http://dx.doi.org/10.1016/j.cemconcomp.2013.10.016

[13] Rezvani, M., Proske, T. & Graubner, C. A., Modelling the drying shrinkage of concrete made with limestone-rich cements, Cement and Concrete Research, 115, 2019, 160–175. https://doi.org/10.1016/j.cemconres.2018.09.003

[14] Radović A., Structural concrete with reduced cement and high limestone powder content, Faculty of Civil Engineering, University of Belgrade, 2025, Doctoral dissertation.

[15] Radović, A., Marinković, S. & Savić, A., Compressive strength of green concrete with low cement and high filler content, Building Materials and Structures, 64, 2021, 93–108. https://doi.org/10.5937/GRMK2102093R

[16] Radović, A., Marinković, S. & Tosić, N., High-volume limestone powder concrete as a low-carbon material for reinforced concrete beams: Experimental evidences and code predictions of long-term behaviour, Construction and Building Materials, 514, 2026. https://doi.org/10.1016/j.conbuildmat.2026.145582

[17] Radović, A., Carević, V., Radević, A., Stupar, B. & Veličkov, D. Influence of curing period on some mechanical and durability-related properties of limestone powder concrete, Building Materials and Structures, 67(3), 2024, 111-121. https://doi.org/10.5937/GRMK2400007R

[18] Dhir, R. K., Limbachiya, M. C., McCarthy, M. J. & Chaipanich, A., Evaluation of Portland limestone cements for use in concrete construction, Materials and Structures, 40, 2007, 459–473. https://doi.org/10.1617/s11527-006-9143-7

[19] Tošić N., Behaviour of reinforced concrete beams made with recycled and waste materials under long-term loading, Faculty of Civil Engineering, University of Belgrade, 2017, Doctoral dissertation.

[20] Dragaš J., Ultimate capacity of high-volume fly ash reinforced concrete beams, Faculty of Civil Engineering, University of Belgrade, 2018, Doctoral dissertation.

[21] Carević V., Influence of cracks on the deterioration mechanisms and durability of reinforced concrete structures, Faculty of Civil Engineering, University of Belgrade, 2020, Doctoral dissertation.

[22] Radović, A., Carević, V., Marinković, S., Plavšić, J. & Tešić, K., Prediction model for calculation of the limestone powder concrete carbonation depth, Journal of Building Engineering, 86, 2024, 108776. https://doi.org/10.1016/j.jobe.2024.108776

[23] Radović, A., Carević, V. & Savić, A., Accelerated and natural carbonation of high-volume limestone powder concrete: an experimental study, Building Materials and Structures, 69(2), 2026, 233–246. https://doi.org/10.5937/GRMK2600015R

[24] Carević, V., Marinković, S., Plavšić, J. & Radović, A., Service Life Design of Concrete Structures Made of High-Volume Limestone Powder Concrete—Case of the Carbonation-Induced Corrosion, Buildings (MDPI), 13(12), 2023, 3112. https://doi.org/10.3390/buildings13123112

[25] Radović, A., Carević, V. & Marinković, S., Impact of the water-curing time on the carbonation initiation period of high-volume limestone powder concrete, Building Materials and Structures, 68(2), 2025, 73-81. https://doi.org/10.5937/GRMK2500004R

[26] EN 1992-1-1, Eurocode 2: Design of concrete structures - Part 1-1: General rules - Rules for buildings, bridges and civil engineering structures, Final draft, European committee for standardization, Brussels, 2023.

[27] Hafez, H., Kurda, R., Al-Ayish, N., Garcia-Segura, T., Cheung, W. M. & Nagaratnam, B., A whole life cycle performance-based ECOnomic and ECOlogical assessment framework (ECO2) for concrete sustainability, Journal of Cleaner Production, 292(126060), 2021. https://doi.org/10.1016/j.jclepro.2021.126060

[28] Radović, A., Hafez, H., Tošić, N., Marinković, S. & de la Fuente, A., ECO2 framework assessment of limestone powder concrete slabs and columns, Journal of Building Engineering, 57, 2022, 104928. https://doi.org/10.1016/j.jobe.2022.104928