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Influence of curing period on some mechanical and durability-related properties of limestone powder concrete

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ABSTRACT

This study investigates the influence of curing periods on the mechanical and durability-related properties of limestone powder concrete, focusing on the potential of limestone as a sustainable alternative to traditional materials, primarily cement. The research explores the effects of varying cement replacement percentages (30-55%) and curing durations (1, 3, 7, 14, and 28 days) on concrete properties such as compressive strength, flexural strength, water permeability, and resistance to chloride ingress. The limestone fineness was also tested using two powders from the same chemical composition, but different particles size. Results indicate that longer curing periods generally enhance concrete performance, but not in all cases. The greatest benefits of extending the curing period was observed in the case of water penetration depth, so the average difference between 1 and 28 days curing was about 50%. Flexural strength also saw a substantial increase of up to 24% over the same curing period. However, increasing the curing period from 7 to 28 days resulted in an unexpected average reduction in concrete compressive strength of 13%. Despite previous results, a positive impact of a higher limestone powder content was observed in all cases, except for resistance to chloride penetration. Concretes that contained limestone powder had a significantly lower (as much as 186%) resistance to chloride penetration, compared to the reference (with the highest dispersion of results). The study found no significant influence of limestone particle size on concrete properties.

1 Introduction

The construction industry, particularly the concrete sector, significantly impacts the environment due to its extensive use of raw materials, high energy consumption, and substantial waste production. With an annual production nearing 35 billion tons [1], [2], the concrete industry is a major contributor to environmental degradation, primarily through the use of natural stone aggregates and the large carbon dioxide (CO_2) emissions from cement production [3]. Moreover, cement production alone accounts for approximately 7-10% of all anthropogenic CO_2 emissions [4], making it one of the most carbon-intensive industries globally. Efforts to address these environmental impacts have led to a growing emphasis on finding sustainable alternatives to traditional processes and materials within the concrete industry. This transition is crucial for achieving a carbon-neutral future and addressing the urgent need to combat climate change. To improve the sustainability of concrete production, there has been a focus on reducing the clinker content in cement by using supplementary cementitious materials (SCMs) such as fly ash and ground granulated blast furnace slag (GGBS), [5]. These materials can partially replace ordinary Portland cement (OPC), thus reducing CO_2 emissions. However, the availability of SCMs is limited, and their supply is expected to decrease as coal-fired power plants are phased out and the steel industry's slag production declines [6], [7]. This scarcity necessitates the investigation of alternative, eco-friendly materials, such as finely ground limestone (LS), despite their lower reactivity, even inertness [8], and potentially negative impact on the mechanical and durability properties of concrete [9]. Therefore, the key challenge remains to balance environmental and economic benefits with the technical performance requirements of concrete [10].

Replacing OPC with LS powder can significantly influence the workability of concrete. While high replacement

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percentages of OPC with LS powder (30-55%) can decrease workability [11], [12], applying suitable water-reducing admixtures and adjustments in the mix design can mitigate these effects [13]–[16]. The fine particles of limestone fill voids between cement grains, reducing the water demand and improving the fluidity of the mix [17]. Some studies [18]–[20] suggest that the incorporation of LS powder, especially in combination with the appropriate powder paste (OPC + LS + water) volume and a dose of superplasticizer, can maintain or even enhance concrete workability, making it easier to cast and place.

The role of LS powder on the compressive strength of concrete is multifaceted. At lower replacement levels (up to 10-20%), limestone powder can improve compressive strength by enhancing particle packing and providing nucleation sites for cement hydration, resulting in a denser and stronger microstructure [8], [21]. Some other studies have shown that even replacing OPC with a high LS powder content (40-60%), while reducing water and increasing superplasticizer content, can achieve comparable or even higher compressive strength [11], [12], [17], [20], [22]. Additionally, the particle size distribution of LS powder plays a significant role; finer particles enhance higher strength due to better packing density and acceleration of initial hydration [9], [12], [21], [23]. It is essential to carefully manage the amount of LS powder, the quantity of paste, and the water-to-cement ratio to ensure comparable strength. Other mechanical properties are usually closely related to the compressive strength [24]–[28].

LS powder affects various durability-related properties through different mechanisms [29]. The water permeability of concrete depends on the degree of cement hydration, the porosity and pores structure of the cement matrix, the quality of the transit zone between the cement matrix and aggregates, but also on the intensity of water pressure [30]. LS powder primarily influences this property by its filler effect, increasing the density and reducing porosity of the concrete matrix [17]. By filling voids and minimizing capillary pores, LS powder has mainly positive effects and decreases the water permeability of concrete [24]. This improvement is better if finer particles are used. However, an excessive replacement ratio can also increase the porosity if not properly balanced with other mix components, potentially compromising the resistance to water penetration [31].

Unlike water penetration, incorporating LS powder as a substitute for OPC has a predominantly negative influence on the resistance of concrete to chloride ingress [16], [24], [31]–[34]. The difference is more pronounced with higher replacement percentages. In this case, the dilution effect becomes prominent [8]. Moreover, the inert nature of limestone powder reduces the overall content of cementitious material, which reduces the aluminate phase and consequently, the concrete resistance. The chemical reaction between LS powder and available aluminates further diminishes the already insufficient aluminate phase, making this effect more expressed [9]. In this type of concrete, the transport of chloride ions by diffusion is also higher [35]. However, Li and Kwan [24] have demonstrated that is possible to make concrete with a high LS contribution (as much as 60%) that possesses better resistance against chloride penetration compared to the reference OPC concrete. This has been accomplished through meticulous mix design and the optimization of powder paste volume.

1.1 Influence of curing on concrete properties

Regardless of the importance of the amount of cement replaced by LS powder, curing of concrete under specific thermo-hygrometric conditions during a certain period after compacting could be pivotal in ensuring the desired concrete performance. Proper curing enhances the hydration process, significantly improving all mechanical and durability-related properties of concrete. Despite its importance, the influence of curing on LS powder concrete properties has been insufficiently investigated. More precisely, a review of the available literature has identified only four studies [16], [36]–[38].

Dhir et al. [16] analyzed the effect of curing on the compressive strength of concrete. Five concrete mixtures with different percentages of cement replacements (0%, 15%, 25%, 35%, and 45% by mass) were prepared and tested. The reference concrete (0% of cement replacement) contained 310 kg/m^3 of cement with a water-to-cement ratio (w/c = 0.6). LS powder concretes maintained the same total amount of powder components (OPC + LS = 310 kg/m^3) and the same water-powder ratio (w/p = 0.6). The samples were cured in water for 1 day, 3 days, 7 days, and 28 days (including initial storage in steel molds covered with plastic film for the first 24 hours). After water curing, the samples were stored under constant laboratory conditions at 20°C and 55% relative humidity (RH). Testing was conducted at 1, 3, 7, and 28 days. The authors emphasized that the samples tested at 3, 7, and 28 days were removed from water 12, 24, and 48 hours before testing, respectively. This was done to achieve the same moisture conditions for all specimens.

The 28-day water-cured OPC mixture had the highest compressive strength (41.0 MPa). Due to the adopted approach (w/p = const), an increase in LS powder content was accompanied by a decrease in compressive strength. Mixtures with 15%, 25%, 35%, and 45% replaced cement had 11%, 28%, 43%, and 59% lower compressive strength, respectively, compared to the reference.

The ratio of compressive strength for the samples cured for "i" days (f_{cm}^{i}) to the corresponding samples cured for "28" days (f_{cm}^{28}), for concretes with different LS powder content, is shown in Figure 1.

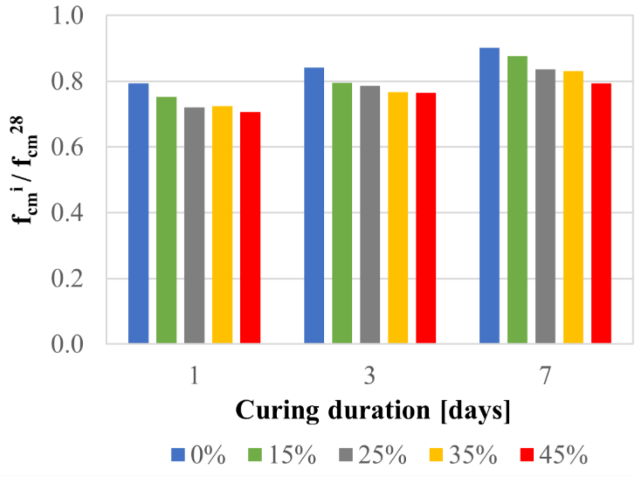

Figure 1. The effect of curing duration on the compressive strength of concrete with different LS powder content, data from [16]

Increasing the curing period positively affects the compressive strength of all tested mixtures. However, this effect is more pronounced in mixtures containing LS powder. OPC mixtures were less sensitive, with strength reductions ranging between 10–20%, while mixtures with 45% LS powder experienced declines of around 20–30%. These conclusions align well with the observations of Sun and Chen [38], but contradict the findings of Bonavetti et al. [39]. Namely, Bonavetti et al. [39] showed that the samples wet-cured for 7 days had higher compressive strength (10–17%) compared to those wet-cured for 28 days. Larger differences correspond to a higher LS powder content. The same study also found that samples air-cured in laboratory conditions throughout had the lowest strength (15–32%), with losses being greater in OPC mixtures than in LS powder concretes. Contradictory findings indicate the need for additional experimental research to clarify these effects.

The same trend as for compressive strength under different curing conditions was observed for tensile strength, [39]. Moreover, these values are almost linearly correlated.

From the aspect of durability, the lack of results is evident. Unfortunately, no paper was found addressing the effects of initial curing on the water permeability of LS powder concrete. The situation was not much better in the case of concrete resistance to chloride penetration.

Sun and Chen [38] investigated the influence of three different curing periods on the resistance of LS powder concrete to chloride ingress. In addition to OPC concrete (400 kg/m^3 cement) three more mixtures containing 8%, 16%, and 24% of LS powder were designed. All concretes were divided into two groups. In the first group, the same w/p ratio (0.45) was adopted. The second group aimed to achieve a similar compressive strength of about 53 MPa, so different w/p ratios were used. Three curing periods were chosen for all concretes: 1) Standard curing period of 28 days under 20°C and 95% RH; 2) 7 days of curing at 20°C and 95% RH, followed by 21 days under laboratory conditions at 20°C and 40–50% RH; 3) 3 days of curing at 20°C and 95% RH, then 25 days under laboratory conditions at 20°C and 40–50% RH.

When considering the standard curing period of 28 days for the first group of samples, the results suggest that LS powder can improve concrete resistance, but only at a low replacement percentage. The mixture with 8% LS had the lowest charge passed, about 6% lower than OPC. This can be explained by the fact that very fine LS powder can affect the interconnections between the pores [39], [40]. However, further increasing the LS content to 16% and 24% reduced the concrete's resistance by approximately 10% and 30%, compared to OPC. According to the authors [38] the high volume of LS powder significantly decreases the hydration products, increasing porosity and pore connectivity.

For the second group, which contained the same strength concretes, the results were different. In this case, OPC showed the worst performance. Increasing the LS content improved the concrete's resistance to chloride ingress. Mixtures with 8%, 16%, and 24% LS powder showed a 17%, 23%, and 29% reduction in charge passed, respectively. It was attributed to the better microstructure provided by a lower w/p ratio that overcomes the negative effects of binder dilutions. Similar observations were obtained for the other curing conditions.

Comparing the results for the same concretes under different curing conditions, the advantages of a longer curing period are undeniable. Deviating from the standard curing conditions and reducing the curing period from 28 to 7 days compromised concrete permeability, increasing the charge passed by an average of 10%. Further shortening the curing period to only 3 days additionally jeopardizes concrete performance. The total charge passed through the specimens increased by about 18% overall.

The further prolongation of the curing period to 90 or 180 days resulted in a significant increase in concrete resistance by 10–20% and 40–60% respectively [31], [38]. However, these long curing periods are not suitable for practical application.

2 Objectives

Although some aspects of the impact of LS powder on concrete properties, such as workability and compressive strength, have been relatively well-analyzed, investigations into durability properties are significantly lacking. Moreover, many studies are limited to low-to-medium LS powder content. The literature review also highlighted a substantial gap in understanding the effect of the curing period on all concrete properties. Therefore, the main objective of this research is to investigate how different curing periods influence the properties of concrete containing a high volume of LS powder (30-55% of the cement content). The potential impact of LS powder fineness was also examined. To achieve this aim, an experimental study was designed to provide a better understanding of the interplay between curing duration and the effectiveness of LS powder in enhancing concrete performance.

3 Experimental procedures

3.1 Materials and methods

Ordinary Portland cement CEM I 42.5R (max 5% additional constituents) according to EN 197-1 [41], with a mean particle size of $d_{50} \approx 11$ μm was used. Two types of commercially available LS powder with the same chemical compositions (98% $CaCO_3$ content) in line with EN 197-1 [41] were applied. The designation of LS powder was adopted according to mean particle size (d_{50}). L_3 corresponds to $d_{50} \approx 3$ μm, which is much finer than cement, while L_{12} had a similar particle size distribution ($d_{50} \approx 12$ μm) to OPC. Natural aggregate was divided into three fractions I (0–4 mm), II (4–8 mm), and III (8–16 mm) which originate from the Danube River. All mixtures contained the same total amount of aggregate (1850 kg/m^3) with the following contribution of individual fractions I (52%), II (21%), and III (27%).

The final composition of the mixtures was determined by the absolute volume method. The mixtures were designed to fulfill the high workability requirements prescribed for consistency class S4 or S5 with a target slump ≥ 200 mm [42]. The workability was controlled by an appropriate dose of second-generation superplasticizer (1-2% powder component).

Since the idea was to compare the properties of different types of concrete with similar strengths, the target mean compressive strength (f_{cm}) 48±4 MPa (measured on a 100 mm cube), was chosen, corresponding to commonly used concrete classes C25/30 and C30/37 [43].

Reference OPC concrete was designed with 334 kg/m^3 cement and w/c = 0.51. Besides that, two groups of LS powder concrete (L_3 and L_{12}) with three different percentages of cement replacement (30%, 45%, and 55%) were made. The higher LS powder content than the replaced cement amount is the result of the volumetric replacement of cement paste. This enabled a parallel reduction of water, and achieving the target workability and strength, despite the significantly reduced amount of cement. The proportioning of the tested concrete mixtures is shown in Table 1.

3.2 Casting, curing, and testing of specimens

After mixing, the workability of each concrete mix was verified by a standard slump test [44]. All concretes were cast into plastic and steel moulds and compacted using a vibrating table. The samples are covered with a plastic sheet and protected from moisture loss. After 24 hours, the specimens were demoulded and stored under different curing conditions for the first 28 days. Depending on the desired test, five different curing conditions were adopted. Curing modes are marked with numbers representing days (1, 3, 7, 14, and 28 days) under standard curing conditions [45]. These are listed and explained in detail in Table 2.

Mechanical properties were determined on samples cured in all five conditions. Compressive strength tests were performed on 100 mm cubic samples at different ages, according to EN 12390-3 [46]. For flexural strength, 28-day-old prismatic specimens (100 x 100 x 300 mm) were tested using a three-point bending test [47].

Durability-related properties were determined on samples cured under three different conditions (1, 7, and 28 days). Water penetration depths were tested on 150 mm cubic samples at 28 days old, after exposure to a water pressure of 0.5±0.05 MPa for 72±2 h [48]. Chloride penetration depths were determined using non-steady-state chloride migration tests [49]. For this purpose, a 50 ± 2 mm thick slice was cut from the central portion of the cylinder (Ø100/H200 mm). After preconditioning, the specimens were placed between catholyte (10% NaCl solution) and anolyte (0.3N NaOH solution) reservoirs and subjected to the appropriate external electrical potential axially. Using the measured chloride penetration depths, non-steady-state chloride migration coefficients (D_{nssm}) were determined.

All tests conducted in this research, considering curing conditions and the age of the concrete at the time of testing, are listed in Table 3 for transparency. All reported results represent the mean values of three measurements.

Table 1. Mix proportions of tested concrete

Concrete mix	m_c [kg/m^3]	m_{LS} [kg/m^3]	m_w [kg/m^3]	w/c [–]	SP [%]
OPC	334	0	171	0.51	1.0
L_3-30	230	200	143	0.62	1.5
L_{12}-30	230	200	143	0.62	1.5
L_3-45	182	252	127	0.70	2.0
L_{12}-45	182	252	127	0.70	2.0
L_3-55	153	285	114	0.75	2.0
L_{12}-55	153	285	114	0.75	2.0

Table 2. Curing conditions of concrete samples

Curing period	Curing (1)	Curing (3)	Curing (7)	Curing (14)	Curing (28)
1 day	M	M	M	M	M
1-3 days	A	W	W	W	W
3-7 days	A	A	W	W	W
7-14 days	A	A	A	W	W
14-28 days	A	A	A	A	W

M – in the mold; **A** – in the air 20°C, 65% RH; **W** – in the water 20°C

Table 3. Conducted tests considering curing conditions and the age of concrete

Age at the time of testing	Curing (1)	Curing (3)	Curing (7)	Curing (14)	Curing (28)
1 day	CS	CS	CS	CS	CS
7 days	CS	/	CS	/	CS
28 days	CS, FS, WP, CP	CS, FS	CS, FS, WP, CP	CS, FS	CS, FS, WP, CP

CS – Compressive strength; **FS** – Flexural strength; **WP** – Water penetration; **CP** – Chloride penetration

4 Results and discussions

4.1 Workability

A well-designed mixtures with an appropriate powder component, customized w/c ratio, and sufficient superplasticizer content ensured excellent workability. The consistency class S5 [42] with a slump value over 220 mm was obtained across all concrete mixtures. However, mixtures with higher percentages of cement replacement demanded more superplasticizer to maintain the same level of workability. This is primarily due to the reduced water content in these mixtures, even though their w/c ratios were higher than those of OPC, owing to the lower cement content. If lower workability is acceptable, the superplasticizer dosage can be reduced. Alternatively, the same effect can be achieved by increasing the water content, though this would result in a decrease in strength.

4.2 Mechanical properties

4.2.1 Compressive strength

In Figure 2, the average compressive strengths at 28 days of age for concrete mixes cured under different conditions are shown. For samples cured in water for 28 days, the measured compressive strengths ranged from 44 MPa to 51.8 MPa, which corresponds to the initial hypothesis of producing concrete mixes with uniform strength.

The curing period of concrete in water up to 7 days had a positive effect on the achieved compressive strength values. The longer the concrete was cured in water, the higher the compressive strength. In contrast, concrete mixes cured in water for 28 days showed lower compressive strength values compared to all other curing regimes. The reason for these unexpected results may be the greater amount of water that the concrete was able to absorb and which remained in the concrete at the time of testing under compressive force. Specifically, the retained water in the concrete, when external load is applied, leads to the development of internal stresses and water vapor pressure, resulting in reduced fracture toughness. Similar conclusions, albeit with different types of concrete, were reached in the studies by [50]–[52]. It is assumed that complete drying of samples cured in water for 28 days would lead to higher compressive strength compared to other curing regimes.

A similar effect is observed in concrete cured in water for 14 days. Except for the L_3-55 mix, all other mixes showed measured values approximately equal to the compressive strengths of concrete cured for 7 days in water.

Figure 3 shows the relationship between the compressive strength of concrete cured under different conditions (f_{cm}^{i}) and the compressive strength of the same type of concrete cured in water for 28 days (f_{cm}^{28}). Both strengths (f_{cm}^{i}) and (f_{cm}^{28}) refer to samples tested at 28 days of age.

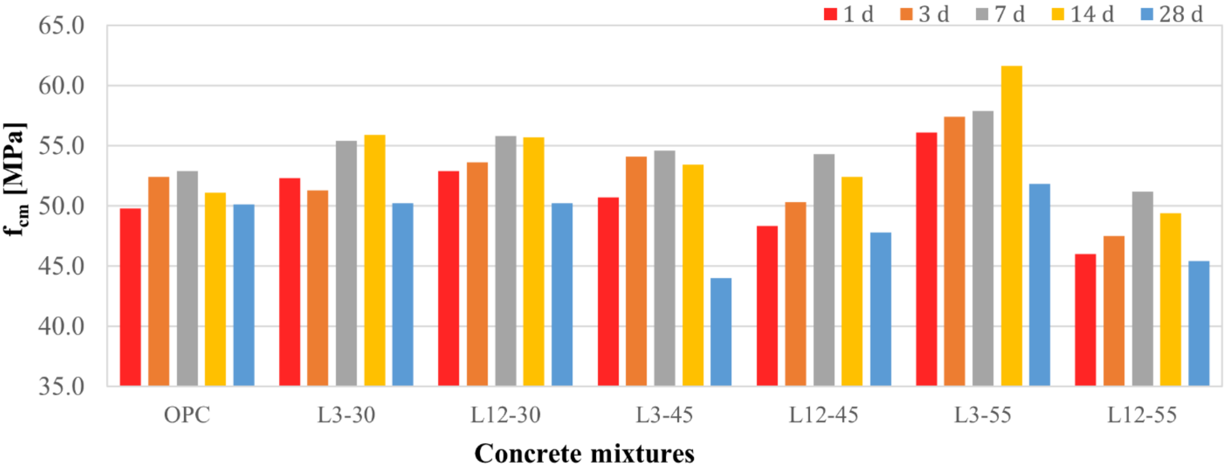

Figure 2. The compressive strength of concrete mixtures with different curing duration at the age of 28 days

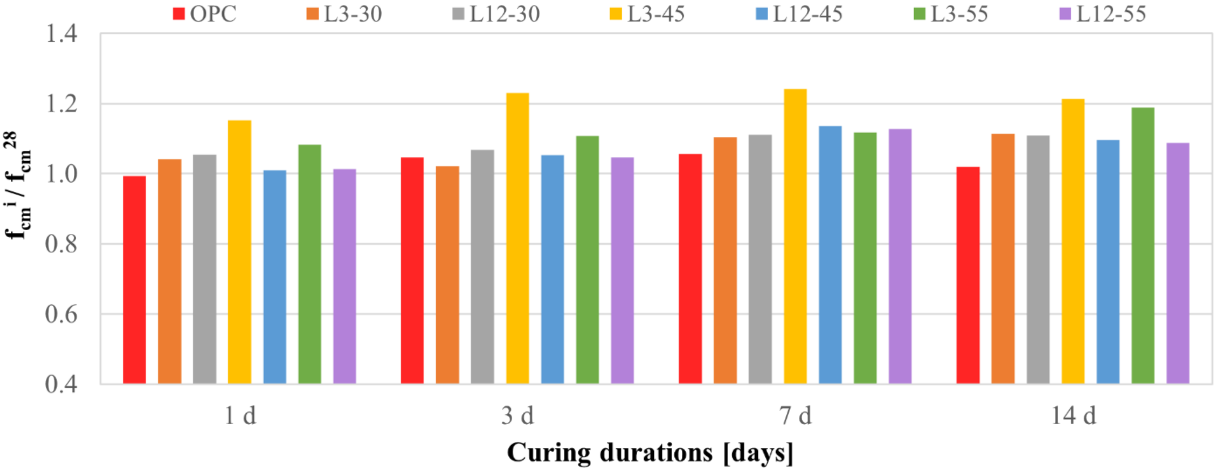

Figure 3. The effect of curing duration on the compressive strength of different concrete mix

As can be seen, the effect of curing had a greater impact on the development of compressive strength in LS concretes compared to OPC concrete. For instance, compared to concrete cured for 28 days in water, the compressive strengths of concrete cured under other conditions range from -0.6% to 5.6% for OPC concrete, from 2.2% to 24.1% for L3 concretes, and from 1.0% to 13.6% for L12 concretes. When comparing only LS concretes, it can be concluded that with an increase in the fineness of the limestone powder used, the sensitivity of the concrete mix to the curing regime also increases. This behavior of the concrete may be due to the relatively small amounts of water used in mixes with a high content of LS powder. Specifically, this water is used not only for cement hydration but also for moistening the LS grains. In mixes with finer LS grains, a larger amount of water is needed because the specific surface area of the grains is greater.

The diagrams of strength gain rates for concretes cured in water for 7 and 28 days are shown in Figure 4. The diagrams clearly show that only the L_{12}-55 mixture exhibits a noticeably slower strength gain in the first three days. In the period from 7 to 28 days, the strength gain rate for LS concretes under pressure is consistent (the lines on the diagram are parallel) and is slightly higher compared to OPC concretes. It can be concluded that different curing regimes did not have a significant impact on the strength gain rate of the tested concretes.

4.2.2 Flexural strength

In contrast to the results of compressive strength tests, the results of flexural strength (see Figure 5) clearly indicate that, with increased curing duration of concrete in water, the measured flexural strengths also increase for most concrete mixtures. These results are consistent with the explanations provided in section 4.2.1, as during flexural tests, a linear force acts on the center of the span of prismatic samples, which does not induce pore pressures in water-saturated samples, unlike in compressive strength tests where such pore pressures have influenced the decrease in these values. The only exceptions are the results obtained from the L_{12}-30 and L_{12}-55 mixtures for samples cured in water for 28 days, as it was found during testing that the rate of load application did not meet the conditions of the EN 12390-5 [47] standard.

If, due to the pronounced effect of pore pressure, compressive strengths of concrete from samples cured in water for 7 days are considered as the reference, a clear correlation can be drawn between the results shown in Figure 5 and the compressive strength results for different concrete mixtures. Specifically, concrete mixtures that had higher compressive strengths logically also had proportionally higher flexural strengths. Additionally, there is no significant impact of the coarseness of the used limestone powder on the obtained bending strength values, which is consistent with the research by Kim et al. [26].

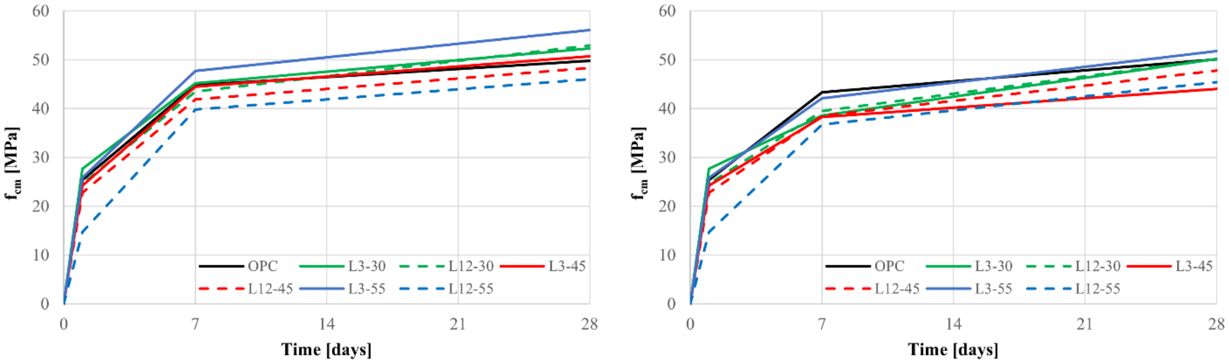

Figure 4. The effect of curing duration on the development of concrete compressive strength: 7 days in water (left); 28 days in water (right)

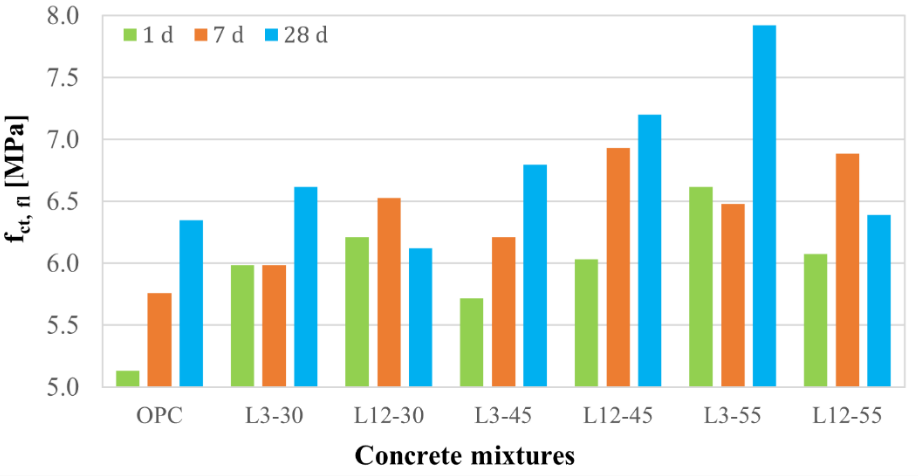

Figure 5. The effect of curing duration on the development of flexural strength maesured at 28 days

4.3 Durability

4.3.1 Water penetration

The measured water penetration values are shown in Figure 6. Compared to OPC concrete, concretes with partial cement replacement by limestone powder exhibited lower water penetration depths. This is attributed to the better "packing" of LS particles, which resulted in concrete with higher density. Other studies also confirm these results [17], [24].

The impact of curing duration on the measured water penetration values is even more pronounced (see Figure 7). For example, OPC concretes cured for 1 and 7 days in water show water penetrations that are 78% and 87% higher, respectively, compared to the same concrete cured for 28 days in water. For LS concretes, these differences range from 38% to 183% for L_3 concretes and from 34% to 114% for L_{12} concretes. However, unlike OPC concrete, LS concretes show a significant difference in measured water penetrations between samples cured for 1 day and those cured for 7 days in water. Additional curing between 1 and 7 days allowed for a reduction in water penetration of up to 50% in LS concretes. These results indicate that, in the case of using limestone powder, proper curing can significantly improve the waterproofness of concrete compared to OPC concretes.

Generally, considering the test results for all mixtures cured in water for 28 days, which aligns with the EN 12390-8 standard [48], all concretes meet the requirement for the waterproof concrete (according to the Serbian national annex of the EN 206 standard [53]). On the other hand, except for the L_3-55 mixture, no other mixture cured in water for 1 day meets the criteria for waterproof concrete. This highlights the importance of proper curing for concrete used in structural elements that are required by the design to be waterproof.

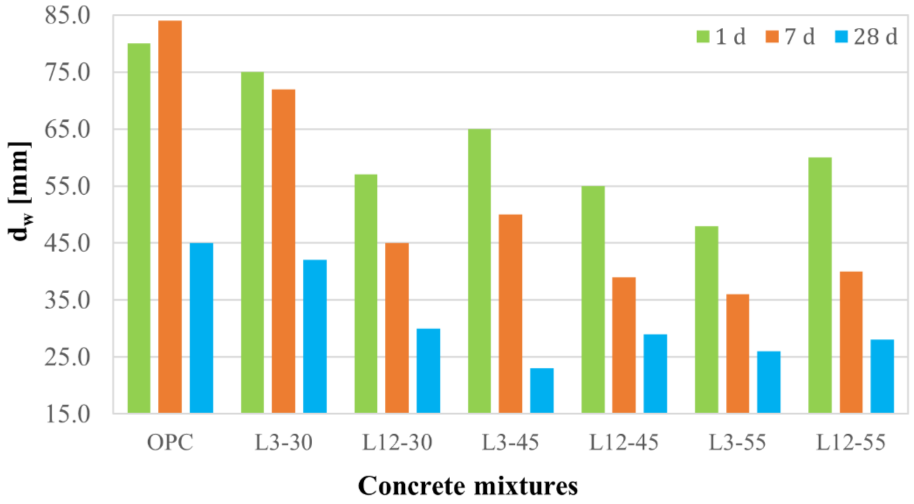

Figure 6. Water penetration depth of concrete mixtures with different curing duration measured at 28 days

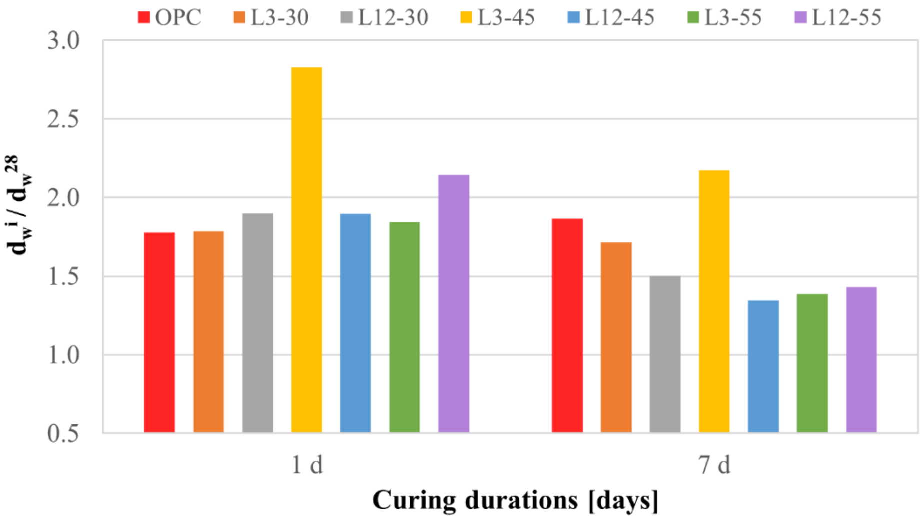

Figure 7. The effect of curing duration on the water penetration depth of different concrete mix

4.3.2 Chloride penetration

The calculated values of chloride migration coefficients (D_{nssm}) are shown in Figure 8. The values were calculated using measured chloride penetration depths, according to EN 12390-18 [49]. With the increase in the curing period, there was a decrease in the chloride penetration depth, and therefore decrease in the migration coefficient. For concrete L_3-30 and L_3-45, 7 days curing period showed slightly better results compared to 28 days curing. However, with OPC concrete, the best results were shown for 1 day curing period, which cannot be explained by physico-chemical processes inside the concrete. Therefore, it is necessary to repeat these and perform additional tests with these concretes in the future.

The results showed that with an increase in the LS replacement percentage, there is no decrease in resistance. Also, there was no significant difference between the types of LS powder. The only difference was observed at 30% replacement of cement with LS. However, LS concretes showed significantly worse chloride penetration resistance compared to OPC concretes. The far worse chloride penetration resistance of LS concretes can be attributed to the reduced content of the aluminate phase [9], [35] and to the dilution effect of the cement paste and increased porosity [8], [54].

The impact of water curing duration on the chloride migration resistance is shown on Figure 9. Curing between 1 and 7 days allowed for a chloride migration coefficient up to 20% in LS concretes. These results indicate that, in the case of using LS powder, proper curing can improve the chloride resistance. However, it is still necessary to look for a way to improve the chloride resistance of these concretes, so that their performances can be closer to OPC concretes.

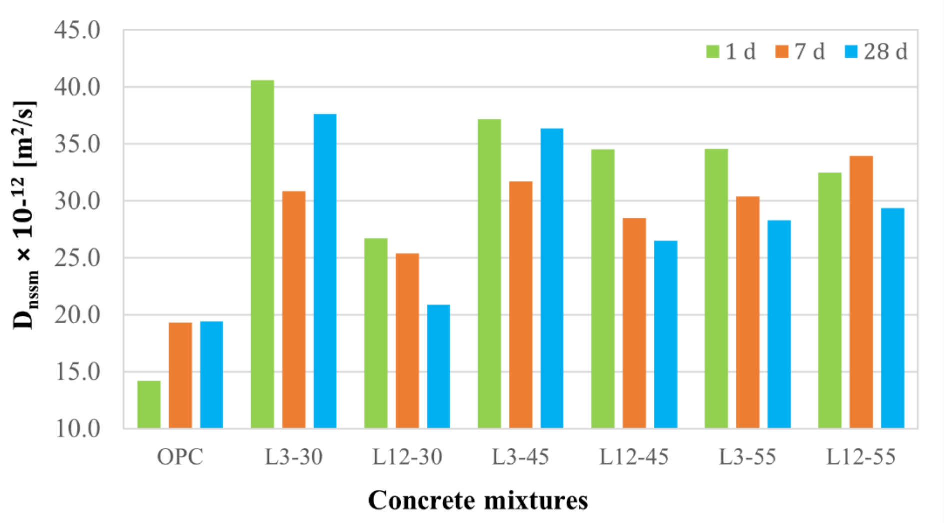

Figure 8. The chloride migration coefficient of concrete mixtures with different curing periods

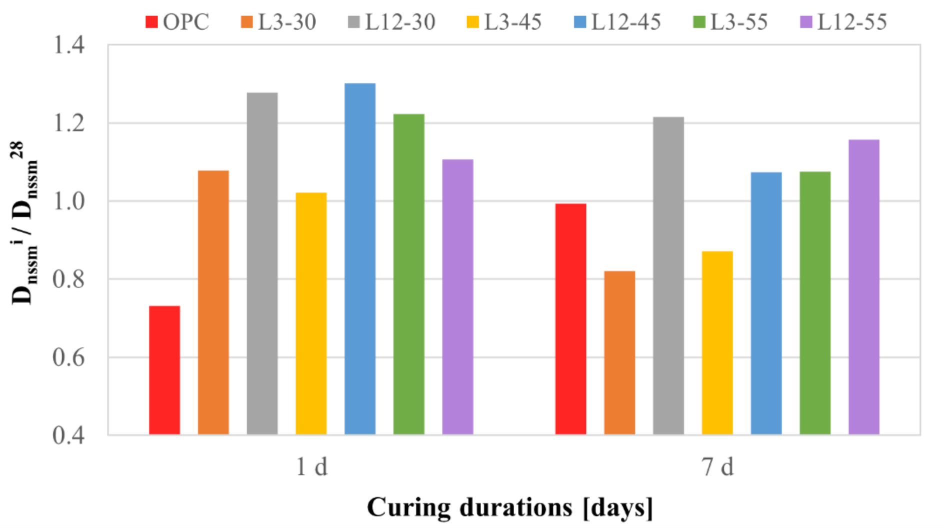

Figure 9. The effect of curing duration on the chloride migration coefficient for different concrete mixtures

5 Conclusions

The main objective of this study was to analyse the impact of different curing periods on the properties of concrete containing a high volume of LS powder (30-55% of replaced cement). The potential impact of LS powder fineness was also examined. An experimental study with five different curing periods (1, 3, 7, 14 and 28 days) and two different LS was designed to examine the interplay between curing duration and the effectiveness of LS powder in enhancing concrete performance. Based on the own experimental results, the following conclusions can be made:

- The curing period of concrete in water up to 7 days had a positive effect on the achieved compressive strength values. The longer the concrete was cured in water, the higher the compressive strength. Contrary to expectations, 28 days of curing did not result in the best concrete performance. Concretes cured for 7 days had an average compressive strength of about 13% higher than concrete cured for 28 days, regardles the LS powder content.
- The effect of curing had a greater impact on the development of compressive strength in LS concretes compared to OPC concrete. When comparing only LS concretes, it can be concluded that with an increase in the fineness of the LS powder used, the sensitivity of the concrete mix to the curing regime also increases.
- The results of flexural strength indicate that with increase in curing period flexural strengths also increase (up to 24%). Additionally, there is no significant impact of the coarseness of the used LS powder on the obtained flexural strength values.
- The positive effect of water curing duration on the measured water penetration was even more pronounced. On average, a 50% less water penetration depth was observed for mixtures cured for 28 days compared to mixtures cured for only 1 day. The obtained results also indicate that, in the case of using LS powder, proper curing can significantly improve the waterproofness of concrete compared to OPC concretes.
- With the increase in the curing period, there was a decrease in the chloride penetration depth, and therefore decrease in the migration coefficient. The results showed that with an increase in the LS replacement percentage, there is no decrease in resistance. Also, there was no significant difference between the types of LS powder. However, LS concretes showed significantly worse penetration resistance chloride (up to 186% with a significant scatter) compared to OPC concretes, which needs to be research in more detail in the future.

CRediT authorship contribution statement:

Andrija Radović: Conceptualization, Formal analysis, Investigation, Methodology, Visualization, Writing - original draft, Writing - review & editing. **Vedran Carević:** Conceptualization, Methodology, Supervision, Writing - original draft. **Aleksandar Radević:** Conceptualization, Funding acquisition, Visualization, Writing - original draft. **Branislav Stupar:** Investigation. **Darko Veličkov:** Investigation.

Declaration of Competing Interests:

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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